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PROJECT APOLLO

SPACECRAFT DEVELOPMENT

STATEMENT OF WORK (4)

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Space Task Group
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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APPENDIX A - SPACECRAFT CHARACTERISTICS (CONTINUED)

1 GENERAL.-

1.1 Purpose.- This document describes the tasks required of the Apollo spacecraft Contractor and the technical framework within which these tasks shall be accomplished.

1.2 Objectives.- The ultimate objective of Project Apollo is the landing of men on the moon, limited observation and exploration of the moon by the crew in the landing area, and safe return to earth. Intermediate objectives of the project include scientific observations in the earth-moon space and lunar reconnaissance prior to lunar landing. It is expected that these objectives will be accomplished from a combination of earth orbital, circum-lunar, lunar orbital, and lunar landing missions. In addition to achieving these primary objectives, it is intended that the Apollo spacecraft be designed so that it will be adaptable for use as an earth orbital vehicle for conducting a variety of scientific and technological services.

1.3 Project.- Project Apollo is a multiphase project with each phase serving to the extent possible as qualification for the subsequent phases. Major milestones in implementation of the project are shown in table 1. The various project phases are planned to overlap and are as follows:

1.3.1 Phase A.- The Phase A spacecraft will be designed for lunar landing and return. Phase A, however, will be limited to manned, low altitude earth-orbital flights of up to two-week duration, and unmanned reentry flights from super-orbital velocities. Both types of flights will be accomplished with the Saturn C-1 launch vehicle. The first portion of this phase, approximately the first year, will include contractor and subcontractor efforts emphasizing detail design and analysis, preparation of detail specifications, development of special manufacturing techniques, and the fabrication of breadboards, hardware for tests, laboratory models, "test" spacecraft, certain long lead items, and a detailed engineering mockup. The specific objectives of Phase A are as follows:

1.3.1.1 Qualification of systems and features for the lunar landing mission within the constraints of the earth orbital environment.

1.3.1.2 Qualification of the heat protection and other systems for the lunar mission through the conduct of reentry tests from superorbital velocities.

1.3.1.3 Study of physiological and psychological reactions and the capability of personnel under extended periods in the space environment.

1.3.1.4 Development of the flight and ground operational techniques and equipment for space flights of extended periods.

1.3.1.5 Conduct of experimental investigations as needed to acquire information for the lunar mission.

1.3.2 Phase B.- This phase will consist of circumlunar, lunar orbital and parabolic reentry test flights employing the C-3 launch vehicle for the purpose of further development of the spacecraft and operational techniques and for lunar reconnaissance.

1.3.3 Phase C.- This phase will consist of manned lunar landing and return missions employing either Nova class launch vehicles or C-3 launch vehicles using rendezvous techniques for the purpose of lunar observation and exploration.

1.4 Summary of Contractor's Tasks.- The Contractor's tasks as delineated in Section 3 of this Statement of Work are summarized in the following paragraphs. This summary is not intended as authorization for the Contractor to perform any work. The Contractor's tasks delineated in the Statement of Work are separated into the categories of design, manufacture, and operations. For the purposes of clarity it should be noted that the spacecraft is comprised of several major parts; command, service, and lunar landing modules, and an adapter. For certain earth-orbital flights, a space laboratory shall be incorporated in the adapter. Definition of these and other terms used in this document is presented in Section 5.

1.4.1 Design.- The Contractor shall design the command module, service module, and spacecraft adapter with their associated GSE excluding the navigation and guidance system, research and development instrumentation, and scientific instrumentation; conduct a development and test program; design the "test" spacecraft for use with Saturn C-1 research and development launch vehicles; and integrate the spacecraft modules and integrate these modules with their GSE, assure compatibility of spacecraft with launch vehicle and with the ground operational support system.

1.4.2 Manufacture.- The Contractor shall manufacture the command module, service module, and the spacecraft adapter with their GSE excluding the navigation and guidance system, research and development instrumentation, and scientific instrumentation; the "test" spacecraft; and mockups. The space laboratory and lunar landing modules will be manufactured by other NASA Associate Contractors.

1.4.3 Operations.- The Contractor shall prepare the spacecraft for flight, man the systems monitoring positions in the ground operational support system, and support the operation of the overall space vehicle.

2 TECHNICAL GUIDELINES.- The guidelines in this section present the technical framework within which the Apollo spacecraft and systems shall be planned and designed. These guidelines are broad in nature, generally affecting features of both flight and ground systems or several subsystems. The various guidelines apply to the Contractor according to the specific assigned tasks delineated in the Contractor's Tasks Section. In addition to these guidelines, specific spacecraft characteristics, design criteria data, and typical flight plan data are presented in Appendices A, B, C, and D. Information on the planned launch vehicles and ground operational support system are presented in reference form.

2.1 Space Vehicle Concept.-

2.1.1 Launch Vehicle.- The Saturn C-1 launch vehicle described in reference 1 shall be the basic launch vehicle for Phase A; however, other launch vehicles may be used for certain development and/or qualification flights. Subsequent project phases will employ C-3 and NOVA class launch vehicles. Descriptive information on these planned launch vehicles is presented in reference 2.

2.1.2 Spacecraft.- The spacecraft shall be composed of separable modules such that 1) "effective weight" principles can be realized through proper jettisoning of expendable units, and 2) module configurations peculiar to specific missions can be modified without substantial effect upon modules common to general missions. The general features of the spacecraft are described in the following paragraphs. Appendix A presents a description of the characteristics of the spacecraft and its systems.

2.1.2.1 Command Module.- The spacecraft shall include a recoverable command module which shall remain essentially unchanged for all Apollo missions.

2.1.2.1.1 Command Center.- The command module shall be the space vehicle command center where there are exercised all crew-initiated control functions. As the command center, this module shall contain the communication, navigation, guidance, control, computing, display equipment, etc., requiring crew mode selection. In addition, other equipment required during nominal and/or emergency landing phases shall be included in the command module.

As the command center, this module shall include features which allow effective crew participation such as windows with a broad field of view for general observation, landing, and rendezvous; equipment arrangements allowing access for maintenance; and simple, manually operated functions in lieu of complex automation.

2.1.2.1.2 Housing.- The command module shall house the crew during all mission phases and shall contain those experimental measurements obtained during flight to satisfy mission objectives.

2.1.2.1.3 Reentry and Landing.- The command module shall be the reentry and landing vehicle for both nominal and emergency mission phases. The use of equipment such as ejection seats or personal parachutes is not precluded for certain cases.

2.1.2.1.4 Ingress and Egress.- Ingress and egress hatches to the command module shall not be obstructed at any stage of space vehicle countdown, flight, and recovery. Means of egress to free space without decompression of the entire command module shall be provided.

2.1.2.2 Service Module.- The spacecraft shall include an unmanned service module for all missions except super-orbital-velocity reentry tests. This unmanned module shall contain stores and systems which do not require crew maintenance or direct operation, and are not required by the command module after separation from the service module. Some consideration shall be given to in-flight maintenance of equipment in the service module by crewmen in extra-spacecraft suits. The service module may be modified in accordance with particular mission requirements, but the principal structural load paths, geometric arrangement, and configuration shall remain unchanged for various missions and project phases. It is expected that the service module would normally be jettisoned prior to reentry into the earth's atmosphere. The service module shall not be recoverable.

2.1.2.2.1 Systems and Stores.- The service module shall contain a reaction control and vernier propulsion system. It shall also contain stores for certain command module systems such as the environmental control system, and major elements of the electric power system. These systems shall be the same for all missions.

2.1.2.2.2 Mission Propulsion Units.- The service module shall contain additional propulsion units to augment the vernier propulsion system and, they shall vary in size and/or number depending upon particular mission requirements. The combined maximum propulsion capability is for return from the lunar surface. The propulsion capability for lunar landing will be provided in a separate module.

2.1.2.3 Lunar Landing Module.- The spacecraft shall include a lunar landing module for the lunar landing missions.

2.1.2.4 Spacecraft Adapter.- The spacecraft adapter shall structurally and functionally adapt the service module or lunar landing module to the launch vehicle for the nonlunar landing and lunar landing configurations, respectively. The spacecraft adapter shall be designed to permit the incorporation of the space laboratory module.

2.1.2.5 Space Laboratory Module.- The spacecraft for certain earth-orbital flights may include a nonrecoverable space laboratory module in which various special tests may be performed. The space laboratory module shall be essentially cylindrical and shall be incorporated within the spacecraft adapter. The space laboratory module shall be compatible with the structural functions of the adapter.

2.1.2.5.1 Support Systems.- The space laboratory module shall have on board sufficient equipment to satisfy its own requirements, manned and unmanned, without demand upon spacecraft equipment.

2.1.2.5.2 Ingress and Egress.- The space laboratory shall have a hatch suitable for ingress and egress to free space and for connection with the spacecraft.

2.2 Operational Concept.-

2.2.1 Mission Profiles.- The spacecraft shall be designed with the capability of performing a variety of missions including earth orbital, circumlunar, lunar orbit, and lunar landing. A description of the characteristics of a lunar landing and return flight plan is presented in Appendix B.

2.2.2 Manning of Flights.- The spacecraft shall be designed for manned operation with no system requirement for unmanned missions. Where unmanned development flights are required specially equipped spacecraft will be used.

2.2.3 Onboard Command.- The primary command and decision-making responsibility shall be on board the spacecraft. The spacecraft shall have the capability to perform the mission independent of ground based information. This shall not preclude the use of ground based information for crew use to increase reliability, accuracy, and performance.

2.2.3.1 Flight Crew.- The flight crew shall consist of three men each of which may be as large as the 90th percentile as defined in reference 3.

2.2.3.2 Crew Participation.- The flight crew shall control or direct the control of the spacecraft throughout all flight modes. They shall participate in navigation, control, monitoring, computing, repair, maintenance, and scientific observation when advantageous. Status of systems shall be displayed for crew assessment and operational mode selection including spacecraft and launch-vehicle-systems status, staging sequences, and touchdown control. The spacecraft shall be designed so that any single crewman will be able to perform all tasks essential to return the command module.

2.2.3.3 Crew Mobility.- The onboard command guideline requires a considerable degree of crew mobility. Towards this end, a "shirtsleeve" environment shall be provided during all noncritical flight phases and any special personal equipment shall not hamper or interfere with the crew's utility or exercise of spacecraft control. In this regard, medical monitoring instrumentation within the command module shall be for the purpose of crew safety and shall be programed on a selective and/or intermittent basis. This guideline does not preclude consideration of continuous or more extensive measurements for particular experiments.

2.2.3.4 Automatic Systems.- Automatic systems shall be employed to obtain precision, speed of response, or to relieve the crew of tedious tasks; but crew monitoring of these systems with provisions for crew override or mode selection is required.

2.2.3.5 Abort Initiation.- Initiation of abort and subsequent control of abort modes shall be primarily the responsibility of the crew. There shall be no abort responsibility assigned to ground command or automatic systems except during prelaunch and launch periods if there is insufficient time for crew action. In such event, abort may be initiated without crew cognizance but subsequent flight control shall be the responsibility of the crew. Automatic and manual abort sequence modes shall be available for crew selection.

2.2.4 Flight-Time Capability.-

2.2.4.1 Flight Period.- The spacecraft systems shall be capable of performing at their nominal design performance level for a mission of 14 days without resupply.

2.2.4.2 Postflight Period.- The command module shall provide a habitable environment for the crew for 72 hours after landing on water or land.

2.2.5 Landing.- The spacecraft shall have the capability of initiating a reentry and landing maneuver at any time during either lunar or orbital missions. Prior to each flight, a primary ground landing site and a suitable backup landing site will be selected to account for weather factors for normal mission landing. Additional criteria apply as follows:

2.2.5.1 Lunar Missions.- Alternate landing sites shall be designated prior to flight such that a landing is possible at these sites when inadvertent reentry situations are encountered.

2.2.5.2 Earth-Orbital Mission.- The spacecraft shall be capable of landing at the primary landing site (or at the backup site) from at least three orbits per day. In addition, alternate sites will be designated such that at least one alternate site can be reached for a landing from each orbit.

2.2.6 Ground Monitoring and Communication.-

2.2.6.1 Earth Orbital Missions.-

2.2.6.1.1 Monitoring.-

2.2.6.1.1.1 Powered Flight.- There shall be continuous tracking and monitoring of onboard system and crew status during powered flight.

2.2.6.1.1.2 Orbital Flight.- Flight progress, onboard systems operation, and crew status shall be monitored by the ground operational support system a minimum of one contact with the spacecraft per hour.

2.2.6.1.1.3 Planned Reentry.- There shall be continuous tracking of the command module during reentry.

2.2.6.1.2 Ground Communications.- The network shall operate on a centralized control basis. However, each network site shall have the capability of affording complete ground monitoring and support independent of the centralized control concept.

2.2.6.2 Lunar Missions.- Communication and ground tracking shall be provided throughout the lunar mission except where limited by the spacecraft being blanketed by the moon.

2.2.7 Network Facilities.-

2.2.7.1 Apollo Control Center.- All phases of Apollo missions shall be directed from an Apollo Control Center located at the launch site.

2.2.7.2 Communications Center.- All mission communications during Apollo missions shall be controlled by the Apollo Control Center.

2.2.7.3 Tracking and Ground Instrumentation Network.- The Mercury and Minitrack networks, the Deep-Space Instrumentation Facility, and other existing networks shall be used to the maximum extent possible. The current and planned configurations of these networks and facilities are presented in references 4 and 5.

2.3 Reliability and Crew Safety.- Mission reliability and crew safety goals, assuming a launch vehicle reliability of 0.95 and including the effect of ground complex reliability, shall be as follows:

2.3.1 Mission Reliability.- The inherent design probability of accomplishing the mission objectives shall be 0.90.

2.3.2 Crew Safety.-

2.3.2.1 Nominal.- The inherent design probability that none of the crewmen shall have been subjected to environmental conditions greater than the nominal limits specified in Appendix C, shall be 0.90.

2.3.2.2 Emergency.- The inherent design probability that none of the crewmen shall have been subjected to environmental conditions greater than the emergency limits specified in Appendix C, shall be 0.999.

2.4 Design Criteria.- Design and operational procedures shall be conducted in accordance with the design principles, natural environments, and crew requirements given below.

2.4.1 Limit Conditions.- The design limit load envelopes shall be established by superposition of rationally deduced critical loads for all flight modes. Loads envelopes shall recognize the cumulative effects of additive-type loads. No system shall be designed incapable of functioning at limit load conditions.

2.4.2 Command Module Reuse.- The command module and internal systems shall be designed for repeated mission reuse after recovery.

2.4.3 Spacecraft Maintenance.- Spacecraft equipment arrangements allowing inflight maintenance have been stated in the command module guideline. Equipment arrangements, accessibility, and interchangeability features that allow efficient preflight servicing and maintenance shall be given full consideration. Full design recognition shall be given to the durability requirements of spacecraft equipment subjected to the continuous handling and "wear-and-tear" of preflight preparation.

2.4.4 Crew Requirements.- Certain crew requirements or tolerances for both nominal and emergency conditions encountered during the various operational phases are presented in Appendix C.

2.4.5 Natural Environments.- Certain aspects of the natural environment for various operational phases are presented in Appendix D.

2.4.6 Reference Axes.- The reference axes of the spacecraft shall be orthogonal and identified as shown on figure 1.

2.4.6.1 X-Axis.- The X-axis shall be parallel to the nominal launch axis of the space vehicle and be positive in the direction of initial launch flight.

2.4.6.2 Y-Axis.- The Y-axis shall be normal to the Y-axis and positive to the right of a crewman when the crewman is facing towards positive X.

2.4.6.3 Z-Axis.- The Z-axis shall be normal to both the X- and Y-axes and be positive in the direction of the crewman's feet.

3 CONTRACTOR'S TASKS.- The Contractor shall be responsible for design, manufacturing, and operations in relation to the space vehicle, ground support equipment, ground operational support system, and training equipment to the extent stated in the following paragraphs.

3.1 Design.- The Contractor shall conduct design analyses of the complete ground and flight system necessary to assure optimum spacecraft design and compatibility of the spacecraft design with all other parts of the flight and ground systems. Detail design responsibilities are described below. The use of Government Furnished Equipment or Industry Standard Equipment shall be investigated and proposed by the Contractor where feasible and practical. The Contractor shall determine and conduct the research and development program required to support his design effort. He shall request the participation of NASA or other government facilities where appropriate.

3.1.1 Space Vehicle.- The Contractor shall conduct those design analyses of the complete space vehicle system necessary to assure optimum spacecraft design and compatibility of the spacecraft design with the launch vehicle. The Contractor may recommend changes to the launch vehicle if such changes are desirable for space vehicle optimization. The Contractor shall conduct complete analyses of the spacecraft interface requirements to assure compatibility with the launch vehicle.

3.1.1.1 Spacecraft.- The Contractor shall be responsible for the integration of the spacecraft modules.

3.1.1.1.1 Command and Service Module.- The Contractor shall be responsible for the detail design of the command and service modules, with the exception of the navigation and guidance system, the research and development instrumentation, and the scientific instrumentation. The Contractor shall be responsible for integrating the navigation and guidance system, the research and development instrumentation, and the scientific instrumentation designs with the command module; and with the appropriate subsystems of the space vehicle. The Contractor shall also design the "test" spacecraft for use with the Saturn C-1 research and development launch vehicles.

3.1.1.1.2 Space Laboratory Module.- The Contractor shall be responsible for design integration of the space laboratory module into the spacecraft design. This responsibility shall include detail interface design, and design analysis of allowable "envelopes" for space laboratory detail design to assure spacecraft-module and spacecraft-launch-vehicle compatibility.

3.1.1.1.3 Lunar Landing Module.- The Contractor shall be responsible for design integration of the lunar landing module into the spacecraft design. This responsibility shall include detail interface design and design anlaysis of allowable "envelopes" for lunar landing detail design to insure spacecraft-module and spacecraft-launch-vehicle compatibility.

3.1.1.1.4 Spacecraft Adapter.- The Contractor shall be responsible for the detail design of the spacecraft adapter and design integration of the spacecraft adapter into the spacecraft design.

3.1.1.2 Launch Vehicle.- The Contractor's responsiblility in relationship to the launch vehicle shall be limited to that indicated above.

3.1.2 Ground Support Equipment(GSE)- The Contractor's responsibility for the design and integration of GSE for any part of the space vehicle shall be to the same extent as his responsibility for the design and integration of that part of the space vehicle as described in the preceding paragraphs.

3.1.3 Ground Operational Support System.- The Contractor shall perform the following tasks related to the ground operational support system.

3.1.3.1 Analysis of the mission information flow requirements. This shall include all the information generation and transmission between the spacecraft and ground stations.

3.1.3.2 Preparation of performance specifications for the additional equipment or equipment modifications required to the existing ground operational support system.

3.1.3.3 Preparation of a mission operating concept for the ground operational support system including concepts of mission control center operation.

3.1.4 Training Equipment.- The Contractor shall be responsible for the design of certain training equipment required for the training of flight and/or ground personnel as required by the NASA.

3.2 Manufacturing.- The Contractor shall be responsible for the manufacture of the command module, service module, spacecraft adapter, "test" spacecraft, mockups, and models for the research and development program with the exception of the navigation and guidance system, the research and development instrumentation, and the scientific instrumentation. The Contractor shall be responsible for the manufacture of the GSE for the equipment which he furnishes and shall also furnish the training equipment required by the NASA. The Contractor shall be responsible for installing the navigation and guidance system into the command module. The Contractor shall be responsible for conducting complete systems tests on the entire assembly prior to delivery to the launch site. The quality of all equipment manufactured by the Contractor, or his subcontractors, shall be controlled through the establishment and maintenance, by the Contractor, of a quality control system complying with reference 6, substituting NASA Space Task Group for Marshall Space Flight Center.

3.3 Operations.- The Contractor shall support the operations of the Apollo spacecraft. The Contractor's tasks shall be consonant with the participation of the NASA as delineated in Section 4. He shall modify, maintain, checkout, service, and prepare the spacecraft and ground support equipment related to the spacecraft and operate certain prelaunch facilities. He shall analyse the mission operation and recommend procedures and requirements for all mission phases such as prelaunch, launch, flight, recovery, data handling, and debriefing. He shall provide personnel to support the flight operations in ground monitoring of the spacecraft systems. In addition, he shall conduct command module post-flight checks in the recovery area and at its final destination, and shall prepare flight reports on the spacecraft performance with respect to the basic mission.

3.4 Reliability.- As an integral part of the design and development program, the Contractor shall implement a reliability program to help assure compliance with mission reliability and safety requirements. The program shall include the specific tasks outlined below and shall wherever possible be extended to the sub-contractor level.

3.4.1 Apportionment.- The Contractor shall apportion quantitative reliability goals to the various systems of the spacecraft. These goals shall then be used by the Contractor as design parameters for the various systems of the spacecraft.

3.4.2 Reliability and Safety Evaluation.- The Contractor shall conduct a continuous detailed quantitative system analyses to assess adequacy of systems to meet mission reliability and safety goals.

3.4.3 Components.- The Contractor shall implement a planned component parts selection and qualification program with provision for formal component part application review. In addition, the Contractor shall implement a formal scheduled program of design review at appropriate levels of system design and assembly.

3.4.4 Reliability Demonstration.- The Contractor shall demonstrate the reliability of all Contractors-furnished equipment; a specific formal program for accomplishing this shall be set forth in the reliability program plan specified in Appendix E.

3.4.5 Degradation Control.- The Contractor shall establish a formal system of controls designed to minimize degradation of quality during fabrication, test, handling, shipment, maintenance, and operation of flight equipment.

3.5 Logistics.- The Contractor shall be responsible for providing adequate logistics support for the equipment which he furnishes. Logistics support shall include all spares, facilities, and transportation.

3.6 Documentation.- The Contractor shall provide the documentation described in Appendix E. All documentation required shall be classified as one of three types. Type I documentation shall be submitted to the NASA for approval. Type II documentation shall not require approval, but shall be submitted for coordination, surveillance, and/or information. Type III documentation shall be retained by the Contractor and made available to authorized representatives of the NASA for review, upon request.

4 NASA PARTICIPATION.- The Phase A spacecraft contract will be managed by the Space Task Group of the NASA. The scope of Project Apollo requires that a considerable number of NASA contractors and organizational groups will be involved in the implementation of the project. The spacecraft Contractor will require contact with these contractors and groups in order to carry out his responsibilities as described in Section 3. The Space Task Group will arrange the procedures for, and will monitor these contacts. NASA participation in the design, manufacturing, and operational aspects of the project is only defined in the following paragraphs as required to define the Contractor's tasks. It should be noted that "NASA responsibility" as used in this document does not preclude parts of this responsibility being carried out through other NASA contractors.

4.1 Design.- The NASA will participate in the research and development program where government facilities are appropriate.

4.1.1 Space Vehicle.-

4.1.1.1 Spacecraft.-

4.1.1.1.1 Command and Service Modules.- The NASA shall be responsible for the detail design of the navigation and guidance system, the research and development instrumentation, and the scientific instrumentation. It shall provide the spacecraft contractor the necessary information, and arrange the necessary contact with other government contractors to allow integration of the navigation and guidance system, research and development instrumentation, and scientific instrumentation design with the command module design.

4.1.1.1.2 Space Laboratory Module.- The NASA shall be responsible for the detail design of the space laboratory module, within the design "envelopes" developed to assure compatibility of this module with other parts of the space vehicle.

4.1.1.1.3 Lunar Landing Module.- The NASA shall be responsibile for the detail design of the lunar landing module, within the design "envelopes" developed to assure compatibility of this module with other parts of the space vehicle.

4.1.1.2 Launch Vehicle.- The NASA shall be responsible for the design of the launch vehicle.

4.1.2 Ground Support Equipment (GSE).- The NASA's responsibility for the design of GSE for any part of the space vehicle shall be to the same extent as its responsibility for the design of that part of the space vehicle as described in the preceding paragraphs.

4.1.3 Ground Operational Support System.- The NASA shall be responsible for the detail design of equipment required for addition or modification to the existing ground operational support system, consistent with the performance specifications developed to assure flight-ground system compatibility.

4.2 Manufacturing.- The NASA shall be responsible for providing crew personal equipment, food, survival equipment, the navigation and guidance system, the research and development instrumentation, and the space laboratory module, lunar landing module, launch vehicle and their associated GSE. It shall also be responsible for providing all equipment and facilities associated with the GOSS.

4.3 Operations.- The NASA will direct the spacecraft prelaunch, launch, flight, and recovery operations and man all positions in the ground operational support system except the spacecraft systems' monitoring positions. The NASA will provide all spacecraft launch site facilities, overall prelaunch and launch countdown procedures, flight crews, and medical support and arrange for recovery support of Department of Defense and other government agencies.

5 DEFINITIONS.-

5.1 Command Module.- The command module (see the command module guideline) is the portion of the spacecraft which houses the crew, serves as the center for crew-initiated command functions, and serves as the recoverable portion of the spacecraft.

5.2 Emergency Limits.- Emergency limits are defined as the environmental limits beyond which there is a high probability of permanent injury, death, or incapacity to such extent that the crew could not perform well enough to survive.

5.3 Flight.- Flight is defined as the phase of operations beginning with lift-off and ending when the command module lands upon the earth.

5.4 Ground Operational Support System GOSS).- The GOSS is defined as a system of ground stations and complexes that are distributed worldwide and that are implemented and operated so as to provide spacecraft mission support during the launch, flight, recovery, and post-flight phases of operation. The GOSS includes the mission control center and all network facilities providing tracking, recording, communicating, monitoring, and computational support during these mission phases.

5.5 Ground Support Equipment (GSE).- Ground Support Equipment is defined as all equipment required to inspect, test, adjust, calibrate, appraise, gage, measure, repair, overhaul, assemble, disassemble, transport, safeguard, record, store, actuate, service, maintain, launch and otherwise support an end article.

5.6 Interface.- An interface is the physical interaction between two parts, components, subsystems, etc., or any mode of contact between two or more elements, including the crew during any operation of a system through either direct contact or any such as visual, audio, power, etc.

5.7 Launch.- Launch is defined as the phase of operations beginning with the start of the launch countdown and ending at lift-off.

5.8 Launch Vehicle.- The launch vehicle is the portion of the space vehicle that provides the capability for placing the spacecraft at a prespecified velocity, position, and attitude.

5.9 Lunar Landing Module.- The lunar landing module (see the lunar landing module guideline) is that portion of the spacecraft which includes the system required to provide translunar velocity control, propulsion and attitude control for lunar landing, arrestment of lunar impact, and physical support of the spacecraft while on the moon suitable for lunar launch.

5.10 Nominal Limits.- Nominal limits are defined as the environmental limits within which the crews environment shall be maintained during normal operations.

5.11 Nonstressed Limits.- Nonstressed limits are defined as the environmental limits wo which the crew may be usbjected for extended periods of time such as orbit, lunar transit, and periods subsequent to normal landings.

5.12 Postflight.- Postflight is defined as the phase of space vehicle operations beginning with the landing of the command module upon the earth and ending when the final flight test report is completed.

5.13 Prelaunch.- Prelaunch is defined as the phase of spacecraft operations beginning with the time when the space vehicle elements are received at the launch site and ending with the start of the launch countdown.

5.14 Recovery.- Recovery is defined as the phase of spacecraft operations within which the command module and/or crew and other designated elements or components of the space vehicle are located, retrieved, subjected to preliminary postflight examination and care, and transported to the location or locations designated by the NASA.

5.15 Research and Development Instrumentation.- Research and development instrumentation is defined as instrumentation used for the development and qualification of spacecraft systems.

5.16 Scientific Instrumentation.- Scientific instrumentation is defined as instrumentation within the command module for the specific purpose of obtaining scientific data which are not related to spacecraft system operation.

5.17 Service Module.- The service module (see the service module guideline) is the portion of the spacecraft housing the stores and systems which do not require maintenance or direct operation by the crew and are not required by the command module after separation from the service module. This includes the attitude and vernier propulsion systems plus additional propulsion units which vary in size and depending upon particular mission requirements. The propulsive capability of the service module is sufficient for return from the lunar surface.

5.18 Spacecraft.- The spacecraft consists of the command, service, space laboratory, and lunar landing modules including the spacecraft adapter which transmits loads between the spacecraft and launch vehicle.

5.19 Spacecraft Adapter.- The spacecraft adapter (see the spacecraft adapter guideline) is the portion of the spacecraft which structurally and functionally adapts the spacecraft to the launch vehicle.

5.20 Space Laboratory Module.- The space laboratory module (see the space laboratory module guideline) is the portion of the spacecraft specifically designed to provide additional facilities for conducting various tests and experiments during certain earth-orbital flights.

5.21 Space Vehicle.- The space vehicle consists of the spacecraft and launch vehicle.

5.22 Spare Parts.- Spare parts are defined as the material capable of separate supply and replacement which is required for the maintenance, overhaul, or repair of an end article.

5.23 Stressed Limits.- Stressed limits are defined as the environmental limits to which the crew may be subjected for limited periods of time such as launch, reentry, and landing.

5.24 Sustained Acceleration Performance Limits.- Sustained acceleration performance limits are defined as the maximum sustained acceleration to which the crew shall be subjected and still be required to make decisions, perform hand-controller tasks requiring visual acuity, etc.

5.25 "Test" Spacecraft.- "Test" spacecraft are defined as special spacecraft instrumented for conducting research and development spacecraft testing, e.g., orbital and reentry testing with certain Saturn C-1 research and development launch vehicles.

5.26 Type I Documentation.- Type I documentation is defined as the documentation requiring NASA approval.

5.27 Type II Documentation.- Type II documentation is defined as the documentation required for coordination, surveillance, and/or information.

5.28 Type III Documentation.- Type III documentation is defined as the documentation requiring preparation and retention by the Contractor, being made available to authorized representatives of the NASA for review, upon request.

APPENDIX A

SPACECRAFT CHARACTERISTICS

1 GENERAL. - A description of the characteristics of the spacecraft and its systems is presented in this appendix.

2 SPACECRAFT CONFIGURATION. - The physical relationship of spacecraft modules and major components is specified graphically by schematics with identifying notes. Precise arrangements and detailed mechanical features are not intended to be inferred by the figures.

2.1 General Arrangement. - The spacecraft arrangement for lunar landing missions is shown in figure 2. The features pertinent to the terminal phases of lunar landing are not shown.

2.2 Mission Arrangements. - Spacecraft arrangements for the various missions up through lunar landing are shown in figure 3. These arrangements demonstrate system buildup and off-loading techniques convenient to component development and launch vehicle capabilities. External configurations shall be held uniform up to the lunar landing missions.

2.3 Command Module. - The command module physical features are defined by aerodynamic performance requirements and crew utility and well-being considerations.

2.3.1 Geometric Characteristics. - The basic external geometry of the command module is shown in figure 4. The command module shall be a symmetrical, blunt body developing a hypersonic L/D of approximately 0.50. The L/D vector shall be effectively modulated in hypersonic flight. In this example, the modulation is achieved through constant c.g. offset and roll control.

2.3.2 Inboard Profile. - A basic arrangement of crew duty stations and internal features fundamental to full utilization of the command module geometry is shown in figure 5.

2.4 Spacecraft Adapter. - The external geometry, method of attachment, and basic structure shall be identical between spacecraft adapters for all mission configurations. No pressure stabilized structures shall be used.

2.5 Space Laboratory Module. - Spacecraft arrangements utilizing a space laboratory module are limited to earth-orbital missions. A basic geometry of the space laboratory module is shown in figure 6. External geometry of the space vehicle containing the space laboratory module is held uniform with other nonlunar landing mission configurations. An arrangement for "docking" the command module and space laboratory module is shown in figure 7.

3 COMMAND AND SERVICE MODULES SYSTEMS. - The characteristics of the major systems included in the command and service modules are presented.

3.1 Guidance and Control System. - The command module includes a guidance and control system composed of a navigation and guidance subsystem and a stabilization and control subsystem.

3.1.1 Navigation and Guidance System. - The spacecraft interface requirements will be defined on the basis of the studies conducted by the spacecraft Contractor and the Associate Contractor for navigation and guidance subsystem. Some probable interface requirements and system components are:

3.1.1.1 Interface Requirements. -

3.1.1.1.1 Weight. - The command module shall accept a system weight of 400 pounds.

3.1.1.1.2 Power. - The electrical power system shall provide an average of 150 watts with a peak requirement of 600 watts and ten periods of two-hour duration each requiring 350 watts for the navigation and guidance system.

3.1.1.1.3 Cooling. - The cooling provided for the system shall be equivalent to the power consumption specified above.

3.1.1.1.4 View-Ports. - An accessible location in the command module for manual operation of tracking and acquisition devices shall be provided.

3.1.1.2 Components. -

Stable platform
Space sextant
Radar altimeter
Secondary inertial elements
Computer
Periscope
Sun trackers
Associated electronics
Displays and control
Cabling.

3.1.2 Stabilization and Control System. - The functional requirements and a description of the stabilization and control system are presented below.

3.1.2.1 Requirements. - The system shall satisfy the following requirements.

3.1.2.1.1 Atmospheric Abort. - Flight-path control during the thrusting period of atmospheric abort and stability augmentation after launch escape system separation.

3.1.2.1.2 Extra-Atmospheric Abort. - Orientation, attitude control, and reentry stabilization and control. The system shall accept commands from the guidance system for thrust-vector control and reentry control.

3.1.2.1.3 Parking Orbit. - Stabilization of the spacecraft plus the final stage of the launch vehicle while in a parking orbit.

3.1.2.1.4 Translunar and Transearth. - Stabilization and control during midcourse flight both outbound and inbound. The control techniques shall provide fuel economy and shall satisfy navigation, solar orientation, and antenna-pointing requirements. Attitude control shall be provided during application of midcourse corrections. A special control mode may be required during special periods of tracking for obtaining navigation data. In this event, minimum control impulses of 10^{-3} degrees per second or less shall be required plus a requirement that there be no net angular momentum resulting from rotating machinery onboard (or that such machinery can be de-energized for periods of a half-hour or more).

3.1.2.1.5 Orbital Rendezvous and Docking. - Rendezvous and "docking" with the space laboratory module.

3.1.2.1.6 Lunar Landing and Take-Off. - Attitude control for accomplishing landings and take-offs from the moon and for entering and departing from lunar orbits. Attitude control commands shall be accepted from the navigation and guidance system and the crew.

3.1.2.1.7 Reentry. - Control requirements for reentry guidance. Reaction jets will be employed for three-axis stabilization. Reentry control will be provided by rolling the vehicle which is trimmed at maximum L/D.

3.1.2.1.8 Landing. - Stabilizing and controlling the command module with respect to the flight direction in the landing configuration and with respect to the landing system suspension members. Command control will be by the crew employing visual reference.

3.1.2.2 System Description. - The system features flexibility in performance, simplicity in technique, and reliability through redundancy or replaceability of parts. For example, it is desirable to accomplish economical limit cycle performance for stabilization when no disturbances are present, accurate control during periods of large disturbances, and satisfactory maneuver rates for orientation changes all with the same control logic. It is also desirable to have adjustment capability over significant control parameters such as the width of dead band.

3.1.2.2.1 Attitude Reference. - Attitude reference signals may be derived from the navigation and guidance system or from an independent short-term reference system. Compatibility with the signal sources in the guidance system should be insured in either case.

3.1.2.2.2 Operating Characteristics. - The attitude stabilization system shall accept command inputs from the guidance system during periods of thrust-vector control and periods of tracking for navigation purposes.

Consideration should be given to accepting discrete orientation commands from the pilot. The suggested method of maneuvering by the pilot is by opening the outer loop and imposing rate commands on the inner-rate stabilization loop. In this case, consideration should be given to providing an attitude followup for re-engagement of attitude hold when the maneuver is complete. Consideration should also be given to the possibility of utilizing derived rate for stabilization for long periods when rate gyro operation may be costly in power.

3.1.2.2.3 Manual Control. - The preferred arrangement for manual control inputs to the control system is by means of a two-axis hand or finger-tip controller with third-axis control using the feet. Redundancy in controller pick-offs should be provided compatible with overall system redundancy. If satisfactory performance can be obtained, direct electrical control of the valves shall be used. Design of the controls shall provide acceptable feel characteristics for all conditions of the flight environment including the effect of pressure suits when employed and acceleration forces.

3.2 Vernier Propulsion System. - The service module includes a vernier propulsion system to provide longitudinal velocity control not supplied by the reaction control system, mission propulsion system, or lunar landing module; and, to provide effective thrust-vector control during operation of the mission propulsion system. The reaction nozzles are located as shown on figure 2.

3.2.1 Requirements. -

3.2.1.1 Velocity Control. - The system shall provide the propulsion and its own thrust-vector control for the following requirements.

3.2.1.1.1 Launch Escape. - Separation from the launch vehicle during extra-atmospheric launch phases.

3.2.1.1.2 Retrograde. - Velocity decrement required for reentry angles up to 5° from earth orbit.

3.2.1.1.3 Translunar Abort. - Velocity increment not supplied by the mission propulsion system for translunar abort.

3.2.1.1.4 Translunar. - Velocity required for midcourse control not supplied by the reaction control system except when in the lunar landing configuration.

3.2.1.1.5 Transearth. - Velocity required for midcourse control not supplied by the reaction control system.

3.2.1.1.6 Lunar Launch. - Thirty percent of velocity required for lunar launch. The remaining seventy percent shall be supplied by the mission propulsion system. Thirty percent is selected as a near-optimum value for other mission requirements.

3.2.1.2 Thrust-Vectory Control. - The system shall effectively control the thrust-vector during operation of the mission propulsion system.

3.2.2 Description. - The system is pressure fed, utilizes storable hypergolic bipropellants, and is optimized for the lunar launch function including subsequent transearth midcourse control. For all other missions the system will be off-loaded as required.

3.2.3 Control. - The system allows both automatic and manual control of engine ignition, thrust, and cutoff.

3.3 Mission Propulsion System. - The service module includes a mission propulsion system to provide the gross velocity increments not provided by the lunar landing module. (See figure 2.)

3.3.1 Requirements. - The system provides the major portion of propulsion for the following requirements.

3.3.1.1 Translunar Abort. - Velocity increment required for mission abort.

3.3.1.2 Lunar Orbit. - Gross velocity increments required for lunar orbit injection and rejection.

3.3.1.3 Lunar Launch. - Seventy percent of the velocity increment required for earth return.

3.3.2 Description. - The system is comprised of a number of identical solid-propellant rocket motors. The system is optimized for the lunar launch function and off-loaded for lesser requirements. Thrust-vector cnntrol is effectively controlled by the vernier propulsion system.

3.3.3 Initiation. - The initiation and firing sequencing are manually controlled.

3.4 Reaction Control System. - The command and service modules include a reaction control system to provide attitude control, stabilization, ullage for vernier propulsion system, and minor velocity corrections. For mission profiles using a parking orbit before the translunar phase, the spacecraft provides the reaction control required by the S-IV stage of the launch vehicle while in the parking orbit.

3.4.1 Command Module Reaction Control System. - The reaction control system used during reentry and landing flight phases is completely located in the command module but outside the pressurized cabin.

3.4.1.1 Requirements. - The system provides the command module with three-axis attitude control capability prior to the development of aerodynamic moments, roll and yaw attitude control during entry and landing, and pitch and yaw rate damping during reentry and predeployment of the landing system. Angular acceleration at least 14.5°/sec/sec in roll and 16°/sec/sec in pitch and yaw.

3.4.1.2 Description. - The reaction control system is pulse modulated, pressure fed, and utilizes storable hypergolic fuel. Fuel tanks shall be positive expulsion type.

3.4.2 Service Module Reaction Control System. - The reaction control system used for spacecraft control during flight phases other than reentry and landing is located in the service module except for its displays and controls which are in the command module. The system shall provide the dual function of angular and lineal reaction control.

3.4.2.1 Requirements. -

3.4.2.1.1 Angular Reaction Control. - The system provides the spacecraft and S-IV stage of the launch vehicle with angular reaction control for the following requirements.

3.4.2.1.1.1 Preretrograde. - Attitude control prior to initiating retrograde propulsion for earth-orbital and translunar phases.

3.4.2.1.1.2 Translunar. - Attitude control as required for mid-course navigation and control prior to initiation of vernier propulsion. For circumlunar and lunar orbital configurations, the system shall provide pitch and yaw accelerations not less than 2.0°/sec/sec. For lunar landing configurations, the system shall provide pitch and yaw accelerations not less than 0.2°/sec/sec.

3.4.2.1.1.3 Transearth. - Attitude control as required for midcourse navigation and control prior to initiation of vernier propulsion.

3.4.2.1.1.4 Parking Orbit. - Attitude control required during the orbital phase and/or prior to initiation of launch vehicle propulsion before to orbit ejection for lunar landing configurations.

3.4.2.1.1.5 Lunar Orbit Injection and Rejection. - Attitude control required prior to initiation of vernier and mission propulsion for lunar orbit injection or rejection.

3.4.2.1.1.6 Spacecraft Orientation. - Attitude control as required to maintain spacecraft orientation with respect to the sun, earth, or moon sufficient for effective use of power generation, thermal, or communication systems requiring stabilization within 10°.

3.4.2.1.2 Lineal Reaction Control. - The system shall provide the spacecraft and launch vehicle with lineal reaction control for the following requirements.

3.4.2.1.2.1 Ullage Duty. - Lineal acceleration required to settle fuel prior to ignition of vernier propulsion system if required by the vernier propulsion system and except for lunar launch phase.

3.4.2.1.2.2 Translunar and Transearth. - Minor velocity changes as required for midcourse control.

3.4.2.1.2.3 Docking. - Six-direction translation as required for "docking" maneuvers with space laboratory module.

3.4.2.1.3 Description. - The reaction control system is pulse-modulated, pressure fed, and utilizes storable hypergolic fuel. Propellants are identical with propellants used by vernier propulsion system. Propellant tanks are the positive expulsion type.

3.4.2.1.4 Control. - The system provides both automatic and manual control.

3.5 Launch Escape System. - The command module shall be fitted with a launch escape system as shown in figure 2.

3.5.1 Requirements. - The launch escape system separates the command module from the launch vehicle in the event of failure or imminent failure of the launch vehicle during all atmospheric phases. Two critical flight modes are recognized.

3.5.1.1 Pad Escape. - For escape prior to or shortly after lift-off, the launch escape system separates the command module from the launch vehicle and propels the command module to an altitude of at least 5000 feet without exceeding the emergency crew tolerances indicated in Appendix C. There are provisions for lateral displacement.

3.5.1.2 Maximum Dynamic Pressure Escape. - For escape at maximum dynamic pressure, the launch escape system separates the command module from the launch vehicle during thrusting of the launch vehicle and propels the the command module at least 125 feet from the launch vehicle in the first second. The launch escape system and the command module combination are aerodynamically stable or neutrally stable and have sufficient lateral control along any of four previously-selected directions to obtain the maximum possible launch vehicle "miss" distance consonant with the emergency crew tolerances indicated in Appendix C.

3.5.2 Propulsion. - The basic propulsion system is a solid-fuel rocket motor with "step" or regressive burning characteristics. Its nozzles are canted to avoid direct impingement of the exhaust jets on the command module.

3.5.3 Control. - Lateral control, if required, shall be obtained through postnozzle injection to modulate the propulsion motor thrust vector.

3.5.4 Escape System Jettison. - The launch escape system is jettisoned at approximately maximum altitude after "pad escape," or an appropriate time after high dynamic pressure escape, and is separated from the command module by a solid-fuel rocket motor. For normal flights, separation is effected by the main propulsion motor during early operation of the second stage of the launch vehicle.

3.5.5 Initiation and Control Mode Selection. - Initiation of escape and subsequent selection of control modes is the responsibility of the crew. There shall be no responsibility assigned to ground control or automatic systems unless there is insufficient time and/or information for crew action.

3.6 Earth Landing System. - The command module includes an earth landing system to be used under all flight conditions for earth landing requirements. It is also compatible with the use of a moderate L/D terminal landing system such as the "parawing".

3.6.1 Requirements. - The system satisfies the following requirements after normal reentry, maximum dynamic pressure escape, and pad escape.

3.6.1.1 Postentry Stabilization. - Stabilizes the command module during postentry descent.

3.6.1.2 Velocity Control. - Reduces the vertical landing velocity to not more than 30 feet/second at 5000 feet altitude.

3.6.1.3 Impact Attenuation. - Reduces impact acceleration such that neither the command module primary structure or flotation is impaired. Any further attenuation required by the crew shall be provided by individual, crewman shock-attenuation devices. (See paragraph 3.8.3 below.)

3.6.1.4 Postlanding. - The system provides any necessary flotation, survival, and location aids.

3.6.2 Description. - The system consists of a FIST ribbon drogue and a cluster of three simultaneously-deployed, landing parachutes. Landing parachutes are sized such that satisfactory operation of any two of the three will satisfy the vertical velocity requirement. The command module is hung in a canted position from the parachute risers and oriented through roll control to favor impact attenuation.

3.6.3 Initiation and Control. - Initiation of all functions can be manually controlled. Command module roll orientation prior to impact can be also manually controlled.

3.7 Structural System. - In addition to the fundamental load carrying structures, the command and service modules structural system shall include meteoroid protection, radiation protection inherent in the structure, and passive heat protection systems. Primary structures shall be designed and evaluated in accordance with standard aircraft practice with the exception that no structure shall require pressure stabilization.

3.7.1 Loads. - Limit loads are the maximum applied loads that the structure may encounter during its mission. Limit load envelopes are established by superposition of rationally deduced critical loads for all flight and ground handling modes. Load envelopes recognize the cumulative effects of additive-type loads.

3.7.2 Special Limit Loads. - Primary structures are designed for limit loads arising from special flight modes as follows:

3.7.2.1 Tumbling at Maximum Dynamic Pressure. - "Tumbling" of the escape vehicle at maximum dynamic pressure during launch.

3.7.2.2 20g Reentry. - Reentry acceleration of 20g measured along the axis of symmetry.

3.7.2.3 Noise. - Sound pressure levels of 160 db in the frequency range of 37 to 9600 cps emanating from the launch escape system during both launch and escape modes.

3.7.3 <u>Factors of Safety</u>. - Ultimate loads are obtained by multiplying limit loads by an ultimate factor of safety. No structure is designed to fail at less than ultimate load. No structure is designed to yield at less than limit load.

3.7.3.1 <u>Loads</u>. - The factor of safety is not less than 1.5 when applied at limit temperature.

3.7.3.2 <u>Pressure Vessels</u>. - The factor of safety is 2.0 when other applied loads are limit.

3.7.4 <u>Meteoroid Protection</u>. - Meteoroid penetration of structures, tanks, and shields shall be assessed according to the following equation when a single thickness of material is used. Where a double-wall type of structure is used with low-density filling, the required total thickness of the two skins shall be taken as one-third that required for a single sheet.

$$t_s = 3.42\, d_m \left(\frac{\rho_m}{\rho_s}\right)^{2/3} \times \left(\frac{V_m}{C_s}\right)^{2/3}$$

Where: t_s = skin thickness required

d_m = meteoroid diameter, centimeters

ρ_m = meteoroid density (3.5 grams/cc)

V_m = meteoroid velocity, centimeters/sec

ρ_s = density of skin material, grams/cc

C_s = speed of sound in skin material, centimeters/sec.

3.7.5 <u>Reentry Thermal Protection</u>. - The command module's primary thermal protection shall be a charring plastic operating at high surface temperatures to promote radiation. Thermal protection shall be distributed appropriate to local heat fluxes. Heat fluxes towards the interior of the command module shall be passively controlled; no circulatory heat exchange systems shall be employed for primary structures. Egress hatches, windows, umbilicals, etc., shall be located on the low heat flux regions of the command module. (See figure 5).

3.8 Crew Systems. - Example cabin arrangements and support systems directly affecting crew utility and well-being are presented in the following paragraphs.

3.8.1 Duty Stations. - There are two duty stations from which primary operation of the spacecraft can be controlled. These stations are side-by-side with sufficient space between to allow a third station to be occupied during acceleration phases of the flight. The center station is inactive during nominal flight phases and its support and restraint systems retracted into a stowed position. The center "aisle" is thrusly freed for access to work, sanitation, and sleeping areas. (See figure 5.)

3.8.2 Support and Restraint. - Support and restraint systems are provided at each duty station. Support and restraint systems at each station allow free interchange of crewmen with but simple, manual adjustments for individual comfort and ease of fastening.

3.8.3 Impact Attenuation. - Impact attenuation beyond that required to maintain the general spacecraft integrity may be obtained through use of discrete shock mitigation devices for individual crew support and restraint systems.

3.8.4 Pressure Suits. - Each crewman wears full pressure suits during launch, reentry, and similar critical flight phases. The suits are worn over the "shirtsleeve" garment and are the quick-don type. Their inflation pressure is 3.5 psia. When worn inside the spacecraft, ventilation and communication are supplied via umbilicals to the spacecraft systems. Self-contained environmental and wireless communication systems are used for extra spacecraft operation.

3.8.5 Sleeping. - There is a specific cabin area assigned for sleeping. It accommodates a single crewman and is capable of being temporarily partitioned such that cabin noise, light, and other distractions can be minimized. (See figure 5.)

3.8.6 Sanitation. - There is a specific cabin area assigned for sanitation. It accommodates a single crewman and is capable of being temporarily partitioned to afford privacy. Urine and fecal waste are not jettisoned to free space. (See figure 5.)

3.9 Environmental Control System. - The command and service modules include an environmental control system to provide a "shirtsleeve" environment in the command module, a conditioned atmosphere for pressure suit operation, and thermal control of equipment not in the command module.

3.9.1 Requirements. - The system satisfies the following requirements.

3.9.1.1 Metabolic Requirements. - The system satisfies metabolic requirements of the crew for all flight periods.

3.9.1.2 Pressure Suits. - The system provides the atmospheric control required by the individual pressure suits worn during launch, reentry, and other critical flight periods. In event of cabin depressurization, the system provides a conditioned oxygen atmosphere at 3.5 psia.

3.9.1.3 Equipment Cooling. - The system provides thermal control for equipment. No critical equipment depends upon cabin atmosphere for cooling or pressurization.

3.9.2 Description. - The system is diagramed in figure 8 and is as follows:

3.9.2.1 Cabin Atmosphere. - Cabin atmosphere is an oxygen-nitrogen mixture stabilized at 7.0 psia. Oxygen and nitrogen are stored supercritically. The gas supply is sized for two complete cabin repressurizations in addition to leakage. Oxygen from the fuel cell reserve is available for emergency atmospheric use. Sufficient oxygen for reentry is carried in the command module.

3.9.2.2 Carbon dioxide. - Carbon dioxide is removed by lithium hydroxide.

3.9.2.3 Noxious gases. - Noxious gases are removed by activated charcoal and a catalytic burner.

3.9.2.4 Cabin Temperature and Humidity. - Cabin temperature and humidity are controlled by means of a heat-exchanger water-separation system. Heat is transported to an external radiator on the service module by a glycol water loop. Launch and reentry heating are controlled by water evaporation. Ground heating is controlled by Freon from ground support equipment.

3.9.2.5 Water Supply. - Water from the fuel cell is collected as potable water for metabolic and cooling requirements.

3.9.3 Controls. - Control of atmospheric pressures, humidity, and temperature is automatic with provision for manual adjustment and control.

3.10 Electrical Power System. - The command and service modules include an electrical power system to supply, regulate and distribute all electrical power required by the command and service modules for the full duration of flight, including postlanding recovery period.

3.10.1 Requirement. - The system supplies an average of 2.0 KW for all flight periods except reentry and postlanding.

3.10.2 Description. - The system is comprised of non-regenerative hydrogen-oxygen Bacon-type fuel-cell batteries; silver-zinc primary batteries; and associated fuel, distribution, and control equipment. The hydrogen-oxygen fuel cell batteries and their fuel supply are contained in the service module. The silver-zinc primary batteries required during reentry and postlanding are contained in the command module.

3.10.3 Control. - The system operation is automatic. The crew will monitor and perform switching actions to distribute power to the proper buses.

3.11 Communication and Instrumentation System. - The communication subsystem has the capability of transmitting data obtained from the instrumentation subsystem from lunar distances and provides two-way voice and tracking capabilities. A block diagram of the system is shown in figure 9.

3.11.1 Communication Subsystems. -

3.11.1.1 Deep-Space Communication Subsystems. - The subsystem consists of a phase-coherent transponder, a ranging unit, and a RF amplifier; and is compatible with the DSIF ground equipment. When operated with the parabolic antenna from lunar distance, it provides two-way voice, ranging, telemetry, and television with sufficient signal to be compatible with the ground equipment.

3.11.1.2 Telemetry Subsystem. - The PCM telemetry subsystem is selectable and capable of continuous or intermittent operation during any part of the mission. It incorporates sufficient generic flexibility to accommodate initial instrumentation requirements and normal growth, i.e., channel assignment or deletion. The subsytem output is a serial NRZ (C) Pulse Train including digitized high-low level analog inputs, auxiliary digital inputs, events, digital voice, television, and necessary synchronizing data. Under emergency conditions, voice shall be fed directly to the emergency transmitter. Wherever transmission is impractical, all information is recorded onboard. Space requirements are allocated with allowances for a standard IRIG PAN/FM/FM telemetry subsystem to checkout and verify the operation of the PCM subsystem during early Apollo missions.

3.11.1.3 VHF Transmitter and Receiver Subsystem. - The VHF subsystem consists of two identical FM transmitters and receivers and is compatible with the voice and telemetry subsystems and associated VHF antennas.

3.11.1.4 Intercommunication Subsystem. - The intercommunication subsystem is compatible with the premodulation and data multiplexing equipment, transmitting and receiving systems, onboard recorder, ground intercommunication equipment, and the crew headset microphone equipment. It provides two-way communication between individual crew members and the ground stations.

3.11.1.5 Near-Field Transceiver Subsystem. - The subsystem consists of a belt-pack transceiver and a spacecraft transceiver control station, and provides noninterfering two-way voice for in-flight lunar exploration, and two-way rescue voice after earth landing.

3.11.1.6 Television Subsystem. - Real-time television is used for crew monitoring of conditions and displays in remote areas of the space vehicle and for intermittent, programed transmission of crew and spacecraft status to earth. Digital television shall be time shared with voice and capable of both internal and external viewing.

3.11.1.7 C-Band Transponder Subsystem. - The C-band transponder subsystem is compatible with the AN/FPS-16, AN/FPQ-6, and equivalent radars; and provides reliable tracking to 8000 nautical miles when used with associated spacecraft antennas.

3.11.1.8 Altimeter and Rendezvous Radar. - An interrupted, continuous wave X-band radar is used for up-dating the navigation and guidance system in range and velocity in both the lunar approach and rendezvous mission phases. The radar operates in conjunction with the inertial guidance system and provides a radar inertial mixer for this purpose.

3.11.1.9 Minitrack Beacon Subsystem. - A Minitrack beacon is installed as a backup to the primary near-earth tracking system.

3.11.1.10 HF/VHF Recovery Subsystem. - A HF/VHF recovery subsystem compatible with existing military equipments is provided.

3.11.1.11 Antenna Subsystems. - Individual antennas are as follows:

3.11.1.11.1 Tracking. - Flush-mounted, C-band antenna system.

3.11.1.11.2 Deep-Space Communication and Onboard Radar. - LS-X-band fed parabolic antenna housed in service module.

3.11.1.11.3 Near-Earth Phase. - Wide-band, omnidirectional antenna for Minitrack, VHF voice, VHF telemetry, and UHF telemetry in emergency.

3.11.1.11.4 Landing and Recovery. - A whip for HF voice and beacons.

3.11.1.11.5 Extra-Spacecraft Operation. - A flexible whip compatible with near-field transceivers for extra-spacecraft operation.

3.11.2 Instrumentation Subsystem. - The instrumentation subsystem detects and measures events and values adequate for an assessment of crew status, space vehicle performance, and environmental conditions.

3.11.2.1 Sensors. - The sensors selected have an inherent reliability several magnitudes greater than the measured subsystem. Errors contributed by any one sensor to the intelligence data do not exceed 25 percent of the overall system error. Inaccessible measurement areas are provided with both primary and spare sensors and such auxiliary hardware as required.

3.11.2.2 Data Disposition.-

3.11.2.2.1 Telemetry.- Telemetry transmission is upon crew command or by programmed command (e.g., five minutes transmission out of each hour during the coast phase of the mission). Only a small representative group of high-frequency measurements are transmitted in real time. The remaining high-frequency measurements are recorded on broad-band magnetic recorder(s) for possible later coast phase, slow-speed playback at a reduced bandwidth. In addition, provisions are made to record all telemetry data produced during behind-the-moon and reentry phases of the mission.

3.11.2.2.2 Onboard Recorders.- One recorder is provided for the storage of telemetry, voice and video information during periods of RF blackout, and for later playback during permissable periods of RF transmission. A second recorder is used for multichannel recording of high-frequency measurements such as sound and vibration. This recorder may also be used for special purposes in conjunction with the scientific and biomedical instruments.

3.11.2.3 Subsystem Calibration.- A calibration feature is provided as an integral part of the measurement system and is such as to provide a rapid analytic assessment of the measurement system's performance.

3.11.2.4 Auxiliary Instrumentation.-

3.11.2.4.1 Clock.- A real-time, binary-code generating device is provided to act as the primary time reference; to correlate all data; operational and otherwise; and to function as an integral part of all time-critical operations.

3.11.2.4.2 Cameras.- Cameras are included for motion photography of crew status and spacecraft displays for critical and programmed periods, and for documentation during lunar reconnaisance.

3.11.2.4.3 Telescope.- A telescope is provided for operational observation of the lunar surface.

3.12 Scientific Equipment.- The command module allows 10 cu. feet and 250 lbs. for unspecified equipment to be used for scientific observation, measurement, or experimentation.

4 LUNAR-LANDING MODULE SYSTEMS.- The lunar-landing module systems are presented as basic concepts only and are specified to allow sizing of other spacecraft systems.

4.1 Lunar Touchdown System.- The lunar landing module includes a lunar touchdown system to arrest impact, support the spacecraft during its period on the moon, and provide a launching base.

4.2 Guidance and Control System.- The lunar landing module utilizes the guidance and control system contained in the command and service modules.

4.3 Main Propulsion System.- The lunar landing module contains a main propulsion system to provide translunar velocity control and the gross velocity decrement required for lunar landing.

4.3.1 Requirements.- The system satisfies the following requirements.

4.3.1.1 Translunar.- Propulsion for translunar midcourse velocity control.

4.3.1.2 Lunar Orbit Injection.- Propulsion for injection into lunar orbit for landing reconnaissance.

4.3.1.3 Lunar Orbit Retrograde.- Propulsion and thrust-vector control for retrograde from lunar orbit and subsequent velocity and vector control to reach a point 100 feet above the landing site at zero velocity and with a spacecraft attitude compatible with the terminal landing maneuver.

4.3.2 Description.- The system utilizes liquid hydrogen-oxygen propellant.

4.3.3 Control.- The crew participates actively in its control.

4.4 Terminal Propulsion System.- The lunar landing module contains a terminal propulsion System to provide propulsion and attitude reaction control to perform the terminal descent maneuver.

4.4.1 Requirement.- The system satisfies the following requirements.

4.4.1.1 Hover-Descent.- 1.0 minutes of hover-descent time from the 100-foot altitude, zero velocity position.

4.4.1.2 Translation.- 1000-foot translation capability in any direction during any 30 seconds of the hover-descent period.

4.4.1.3 Attitude.- Maintain spacecraft attitude compatible with abort at any phase of maneuver.

4.4.2 Description.- None specified.

4.4.3 Control.- The crew participates actively in its control.

4.5 Structural System.- The lunar landing module structural system meets the same requirements as specified for applicable flight modes of the command and service modules.

5 SPACE LABORATORY MODULE SYSTEMS.- The space laboratory module is required by the technical guidelines to provide its own power supply, environmental control, stabilization, etc., without demand upon the command and service modules' systems.

5.1 Reaction Control System.- The reaction control system aboard the service module will satisfy presently-defined attitude stabilization requirements of the space laboratory. Until more definitive requirements are specified, the Technical Guideline covering this point will be waived and space laboratory attitude stabilization will be provided by the service module.

5.2 Structural System.- The space laboratory structural system shall meet the requirements as specified for the command and service modules.

5.3 Environmental Control System.- The space laboratory includes an environmental control system to provide a "shirtsleeve" environment in the space laboratory and thermal control of space laboratory equipment mounted outside of the pressure cabin.

5.3.1 Requirements.- The system satisfies the following requirements.

5.3.1.1 Metabolic Requirements.- Metabolic requirements of two of the three man crew, except for their food and water which is supplied by the command module.

5.3.1.2 Equipment Cooling. - Thermal control of equipment.

5.3.2 Description. - The environmental control system is the same as used in the command module and as diagramed in figure 8.

5.3.3 Controls. - Control of atmospheric pressures, humidity, and temperature is automatic with provisions for manual adjustment and control.

5.4 Electrical Power Supply System. - The space laboratory includes an electrical power supply system to provide, regulate, and distribute all electrical power required by the space laboratory.

5.4.1 Requirement. - The system provides a continuous power level of 1.5 KW for the nominal sunlit and shadow cycle. For special modes, the system shall supply an average of 1.0 KW for up to three hours continuous shadow operation.

5.4.2 Description. - The system consists of a solar cell array for primary power and a nickel-cadmium battery for secondary power. Voltage and control is compatible with the command and service modules systems.

5.4.3 Control. - System operation is automatic. The crew will monitor and perform switching operations to distribute the power to the proper busses.

APPENDIX B

FLIGHT PLAN

1 GENERAL.- A description of the characteristics of a lunar-landing and return flight plan is presented in this Appendix. The lunar-landing flight plan includes earth-orbital, circumlunar, and lunar-orbital flight plans in that a parking orbit is used prior to insertion on lunar missions; the translunar trajectory is a circumlunar trajectory; and the lunar landing is made subsequent to lunar orbit. The flight plan presented is an example and does not represent design criteria.

2 FLIGHT PLAN CHARACTERISTICS.- The material is presented in terms of the different phases of the flight.

2.1 Lift-Off Conditions.- The launch site is Cape Canaveral, Florida. The time of lift-off for the primary flight plan is 11:42 a.m. $\pm$1 hour, January 12, 1967. The alternate flight plan lift-off time is 11:42 p.m. $\pm$1 hour, January 12, 1967. The launch azimuth is 91°.

2.2 Lift-Off to Parking Orbit.- The characteristics of the flight plan from launch to insertion into a parking orbit at an altitude of 600,000 feet are presented in figures 10 and 11.

2.3 Parking Orbit.- Ground tracks for initial earth orbits having launch azimuth varying from 90° to 105° are presented in figure 12. The parking orbit is circular at an altitude of 600,000 feet. The only portion of the Continental United States over which the spacecraft passes during the first revolution is southern Texas.

2.4 Parking Orbit to Translunar.- The location of the beginning of the insertion phase may be anywhere along the parking orbit depending upon the final conditions that must be obtained. Figure 13 shows earth tracks for two insertion locations: near Africa (figure 13a) and in the mid-Pacific region (figure 13b). The characteristics of the flight plan from the parking orbit to the translunar trajectory are presented in figure 14.

2.5 Translunar and Transearth.- Figure 15 presents the translunar and transearth trajectories for the inertial earth-moon system. The translunar trajectory has the characteristic that if no velocity increment is applied, the spacecraft will return to earth at acceptable reentry conditions. The pericynthion altitude at the moon is 600,000 feet. The return or transearth trajectory shown in figure 15 represents a continuation of the translunar trajectory with a break of 26 hours for landing on the moon and take-off. The transearth and translunar trajectories combined form a reference circumlunar trajectory with proper correction for the lunar time break.

2.6 Lunar Orbit.- The retrovelocity requirements to establish local lunar orbits from the translunar trajectory of figure 15 is presented in figure 16. The velocity increment required to place the spacecraft in a 100-nautical-mile circular orbit from the approach pericynthion altitude of 100 nautical miles is seen to be 3025 ft/sec. The landing site is surveyed as the spacecraft passes over this area during its first revolution. As the spacecraft approaches a point 180° from the landing site, a velocity impulse of 180 ft/sec is applied to place the spacecraft in an elliptic orbit with a pericynthion altitude of 50,000 feet. Figure 17 describes the complete technique from translunar trajectory to the lunar landing phase.

2.7 Lunar Landing.- The lunar landing maneuver is initiated at approximately 50,000 feet altitude. The characteristics of the flight plan during this maneuver are presented in figure 18. The maneuver ends at an altitude of 100 feet at which time the spacecraft vertical velocity is near zero and the horizontal velocity is less than 25 ft/sec. The landing time is dawn on the moon. The landing site is the Sea of Tranquility. Photographs of the moon showing the landing sites are presented in figure 19.

2.8 Lunar Launch to Transearth.- The characteristics of the flight plan from lunar take-off to insertion into a parking orbit at 100,000 feet altitude are presented in figure 20. The transfer from this lunar orbit to insertion into the transearth trajectory is accomplished by the application of a velocity increment of 3110 ft/sec at the insertion point.

2.9 Transearth.- The transearth trajectory is presented in figure 15.

2.10 Reentry.- The return perigee altitude is 120,000 feet, the velocity at perigee is 36,320 ft/sec, and the reference reentry altitude is 400,000 feet. The time at which the reentry altitude is reached is 4:00 p.m., local time, for the primary flight plan of 167 hours after launch. A ground track of the transearth and reentry phase of the flight plan is shown in figure 21. The possible landing area extends from the Western Pacific across the Southern United States and into the South Atlantic. The characteristics of the spacecraft during reentry are for an L/D ratio of .5 and a $W/C_D A$ of 50. The characteristics of the flight plan during reentry are presented in figure 22.

3.10 Impact Acceleration.- The impact acceleration nominal and emergency limits are presented in figures 31 and 32, respectively.

APPENDIX D

NATURAL ENVIRONMENT

1 GENERAL.- Design and operational procedures shall be in accordance with the natural-environment data presented in this appendix. It should be recognized that all natural environment data required for the project are not included herein.

2 LAUNCH.-

2.1 Atmospheric Pressure, Density, and Temperature.- The surface variation of atmospheric pressure, density, and temperature is given in reference D-1.

2.2 Wind.- The direction, magnitude, and cumulative percentage of surface winds are given in reference D-2.

2.3 Precipitation.- The average monthly precipitation is given in figure 33.

2.4 Thunderstorms.- The average number of hours per month during which there are thunderstorms is shown in figure 34.

2.5 Surface Temperature.- The maximum, minimum, and average temperatures are given in figure 35.

3 FLIGHT.-

3.1 Atmospheric Phase.-

3.1.1 Atmospheric Pressure, Density, and Temperature.- The altitude variation of atmospheric pressure, density, and temperature is given in reference D-1.

3.1.2 Wind.- The variation of wind with altitude is given in reference D-2.

3.2 Mission Phase.-

3.2.1 Solar Phenomena.- The hazards associated with an active sun are presented as a model solar event system with an indicated probability of encounter.

3.2.1.1 Model Solar Event System.- The two solar events which occurred on May 10, 1959 and February 23, 1956 form the basis for the model solar event system. The general flux description is shown in figures 36 and 37. The flux energy relationship shall be considered constant over a period of 30 hours for the May 10, 1959 event. The time dependence of the February 23, 1956 event shall be assessed to follow an exponential or inverse t^2 decay law.

3.2.1.2 Probability of Encounter.-

3.2.1.2.1 Double Event.- The probability of encounter of the model solar event system shall be based upon the occurrence of two double events per year with characteristics similar to the May 10, 1959 event.

3.2.1.2.2 Single Event.- The probability of encounter of either of the model solar events occurring singly shall be based on the occurrence of four of the May-type per year and one of the February-type every 4.5 years.

3.2.2 Van Allen Radiation Belts.- A description of the Van Allen radiation belts is presented in figure 38.

3.2.2.1 Inner Belt.- The inner belt is concentrated between the geomagnetic latitudes of 25 degrees North and 25 degrees South. It initiates at an altitude of 500 km and peaks in intensity at an altitude of 8500 km. The proton spectrum at the geomagnatic equator is presented in figure 39. The electron spectrum at the geomagnetic equator is presented in figure 40. The variation of radiation intensity with altitude and geomagnetic latitude is presented in figure 41.

3.2.2.2 Outer Belt.- The outer belt is concentrated between the geomagnetic latitudes 50 degrees North and 50 degrees South. It initiates at an altitude of 15,000 km, peaks in intensity at an altitude of 16,000 km, and decreases to a minimum intensity at an altitude of 21,000 km. The distribution of particles in the heart of the outer belt is presented in table 2, and the electron spectrum is presented in figure 42.

3.2.3 Meteoroid Considerations.- The hazards involved in encountering meteoroids will be assessed on sporadic activity only. The flux considerations for sporadic activity shall be based upon the Whipple distribution presented in table 3.

3.2.4 Electromagnetic Radiation.- Electromagnetic radiation to be used for spacecraft environmental analysis is presented in reference to its source.

3.2.4.1 Solar Radiation.- The electromagnetic radiation from the sun covering the spectrum from 60 angstroms to 1300 angstroms is given in figure 43, from 1300 angstroms to 2000 angstroms is given in figure 44, and from .2 microns to 2.0 microns is given in figure 45.

3.2.4.2 Earth Radiation and Reflection.- The earth's albedo shall be considered as 35 percent. The remaining 65 percent shall be considered to be absorbed and some re-emitted as thermal radiation. The spectrum for the earth's albedo at local noon is given in figure 46. The radiation at the center of the dark side shall be considered to originate from a 251° K black body.

3.2.4.3 Moon Radiation and Reflection.- The moon's albedo shall be considered as 7 percent. The remaining 93 percent shall be considered to be absorbed and some re-emitted as thermal radiation. The radiation shall be considered to originate from a 215° K black body in the area near sunset and a 120° K black body at the center of the dark side.

3.2.4.4 Background Radiation.- The background radiation from celestial sources shall be considered to be 10^{-4} ergs/cm^2/sec in the interval 1230 to 1350 angstroms.

3.2.5 Interplanetary Atmosphere.- The interplanetary atmosphere shall be considered as shown in table 4.

3.2.6 Space Background.- The space background electromagnetic radiation is presented above. The corpuscular radiation shall be considered as shown in figure 47, which represents the cosmic ray flux.

[redacted]

3.2.7 Earth Gravitational and Geometrical Constants.- The following earth gravitational and geometrical constants are to be used for tracking and orbital computations.

3.2.7.1 Symbols.-

a	equatorial radius, cm
f	oblateness factor $=\left(1 - \frac{\text{minor diameter}}{\text{major diameter}}\right)$
g	acceleration of gravity at equator, cm/sec^2
G	universal gravitational constant
h	altitude above the reference ellipsoid, cm
J_n	harmonic terms of the potential function
M	mass
$P_n(\sin \phi)$	Legendre polynomial
ϕ	latitude
r	radius from center of earth, cm
u,v,w	axis system ordinates, cm
U	potential function
λ	longitude
ω	$\frac{2\pi}{L}$, rad/sec
L	length of day, sec
A_u	astronomical constant

Subscripts

e	earth
s	sun
p	planet
m	moon

[redacted]

3.2.7.2 Gravitational.-

3.2.7.2.1 Numerical Values.- In the formula

$$U = (GM_e/r)\left[1 - \sum_n J_n\,(a_e/r)^n\,P_n\,(\sin\phi)\right]$$

Where P_n $(\sin \phi)$ is the Legendre polynomial and ϕ is the geocentric latitude

$GM_e = 3.986032\ (\pm 0.000030)\times 10^{20}\ cm^3/sec^2$

$J_2 = 1082.30\ (\pm 0.2)\times 10^{-6}$

$J_3 = -2.3\ (\pm 0.1)\times 10^{-6}$

$J_4 = -1.8\ (\pm 0.2)\times 10^{-6}$

$J_n = 0.0\ (\pm < 1.0)\times 10^{-6},\ n \geq 5$

$J_{nm} = 0.0\ (\pm < 2.0)\times 10^{-6},\ m \neq 0$

$a_e = 6.378165\ (\pm 0.000025)\times 10^{8}\ cm$

3.2.7.2.2 Remarks.-

3.2.7.2.2.1 The values of GM_e, J_2 and a_e are consistent with the values of geodetic parameters

$f = 1/298.30$

$g_e = 978.030\ cm/sec^2$

3.2.7.2.2.2 The values of a_e, f, g_e are those specified in the DOD World Geodetic System 1960 and are here recommended for sake of consistency. In addition, they are close to the best estimates for these parameters. Reasonable alternative values based on terrestrial geodetic data; e.g., those in reference D-3 differ by less than 20 meters in a_e, .001 cm/sec^2 in g_e, and 0.1 in 1/f.

3.2.7.2.2.3 The value of g_e incorporates a correction of $-.013\ cm/sec^2$ to the Potsdam standard absolute gravity.

3.2.7.2.2.4 The values of J_3 and J_4 are compromises between the values obtained by the principal investigators of satellite orbits as presented in references D-4, D-5, and D-6, with greatest weight to reference D-6, and the given uncertainties are based on the discrepancies between these results. The values of J_2 by these same investigators range from 1082.19 to 1082.79×10^{-6}. The magnitude of effect of the omitted J_{nm} on satellite positions is about ± 400 m or less (see reference D-7).

3.2.7.2.2.5 The most serious discrepancy in determination of gravitational parameters is between the GM from terrestrial data, $3.986032(\pm 0.000030) \times 10^{20e}$ cm^3/sec^2, and that based on the lunar mean motion and the radar measurement of the moon's distance: 3.986141 $(\pm 0.000040) \times 10^{20}$ cm^3/sec^2. This value depends on the moon/earth mass ratio of 1/81.375 (see reference D-8); 3.986048 is obtained from Delano's 1/81.219 (see reference D-9). However, the stated uncertainty depends mainly on the uncertainties in the radar measurement and the lunar radius.

3.2.7.3 Geometrical.-

3.2.7.3.1 Numerical Values.- Figure 48 represents the astrogeodetic geoid data station spacing and distribution. The coordinate system used has its u, v, and w axes earth-centered, earth-fixed, and directed toward the latitudes and longitudes 0°, 0°; 0°, 90° E; and 90° N, respectively.

3.2.7.3.1.1 The corrections to be added to the rectangular coordinates in the u, v, and w system are presented in table 5. These corrections are based on reference D-3.

3.2.7.3.1.2 Stations not connected to any of the principal geodetic systems, but which have an astronomic position or which are connected to a local system must be treated in the following way. The geodetic latitude and longitude is to be that of the astronomic or local system, and the u, v, and w coordinates obtained by the equations

$$u = (\gamma + h) \cos \phi \cos \lambda$$

$$v = (\gamma + h) \cos \phi \sin \lambda$$

$$w = \left[(1 - e^2) \gamma + h\right] \sin \phi$$

where

$$\gamma = a_e \, (1 - e^2 \sin \phi)^{-1/2}$$

$$e = 2f - f^2$$

and h is the elevation above the ellipsoid. If $a_e = 6378165$ meters and $f = 1/298.30$ are used, and the height above the ellipsoid assumed to be identical with the height above sea level, then the standard error of position in the radial direction should be

$$\sigma(r) = \pm 45 \text{ meters.}$$

If the geoid heights from figures 2 or 3 of reference D-3 are added to the height above sea level, then there will be a slight improvement to about ± 35 meters.

For the horizontal coordinates at a station in a geophysically stable continental area

$$\sigma(r\, \phi) = \sigma(r \lambda \cos \phi) \approx \pm 170 \text{ meters.}$$

For the horizontal coordinates from a single astronomic position on an island or in a geophysically disturbed area (mountains, etc.)

$$\sigma(r\, \phi) = \sigma(r \lambda \cos \phi) \approx \pm 350 \text{ meters.}$$

By using the mean position obtained by connecting astronomic observations on opposite sides of an island by traverse this may be improved to about

$$\sigma(r\, \phi) = \sigma(r \lambda \cos \phi) \approx \pm 250 \text{ meters.}$$

By using topographic isostatic corrections of the deflections of the vertical this may further be improved to about

$\sigma(r\, \phi) = \sigma(r \lambda \cos \phi) \approx \pm 200$ meters (for a single station) and

$\sigma(r) = \sigma(r \lambda \cos \phi) \approx \pm 120$ meters(for the mean from observations on opposite sides).

3.2.7.3.2 Remarks.-

3.2.7.3.2.1 The values recommended for Argentina and Australia are based on the assumption of tangency at the geodetic datum "origins" of an $a_e = 6378165+N_o, 1/298.3$ ellipsoid, where N_o is the geoid height at the datum origin given in figures 2 and 3 of reference D-3.

3.2.7.3.2.2 The Vanguard Datum was based on the assumption of tangency to NAD at its origin (97°N, 263°E) of the Hough Ellipsoid

$$a_e = 6378270$$
$$f = 1/297.0$$

3.2.7.3.2.3 The SAO SP 59 datum (see reference D-10) is based on the assumption of tangency to the conventional datums, corrected by gravimetrically computed deflections of the vertical (except in Argentina), of the International Ellipsoid

$$a_e = 6378388$$
$$f = 1/297.0$$

The large differences from reference D-3 datum are due mainly to this use of an obsolete ellipsoid and secondarily to the utilization of much less observational data.

3.2.7.3.2.4 Note that all datum shifts are described as translations; there are no rotations. For properly observed geodetic systems, the orientation error is negligible. Orientation of geodetic systems is obtained from the stars through "Laplace stations," at which astronomic azimuth and longitude are observed.

3.2.7.3.2.5 The standard error for difference of position between two stations connected to the same geodetic control system should always be less than ±20 meters.

3.2.7.3.2.6 The standard errors for astronomic positions in a continental area is based on autocovariance analysis of gravimetry.

3.2.7.3.2.7 The standard error for astronomic positions on islands is based on a sample of 69 islands in the West Indies connected to the continental geodetic system by Hiran trilateration.

3.2.8 Sun and Planetary Constants.- Certain sun, lunar, and planetary constants to be used are presented in table 6.

3.3 Entry, Landing, and Recovery Phase.-

3.3.1 Atmospheric Pressure, Density, and Temperature.- The altitude variation of pressure, density, and temperature is presented in reference D-1.

3.3.2 Wind Velocity.- The wind velocity, which is exceeded only 10 percent of the time, is presented in figure 49 for the months of January and July.

3.3.3 Wave Height.- The wave height, which is exceeded only 10 percent of the time, is presented in figure 50 for the months of January and July.

APPENDIX E

DOCUMENTATION

1\. GENERAL.- The Contractor shall provide the documentation described in the following paragraphs in accordance with the delivery schedules, type classification, and quantities listed in table 7. All documentation required shall be classified as one of three types. Type I documentation shall be submitted to the NASA for approval. Type II documentation shall not require approval but shall be submitted for coordination, surveillance, and/or information. Type III documentation shall be retained by the Contractor and made available to authorized representatives of the NASA for review, upon request. THE PREPARATION OF TYPE I DOCUMENTATION BY THE CONTRACTOR SHALL BE CONDUCTED IN CLOSE COORDINATION WITH THE NASA. IN NO EVENT WILL TYPE I DOCUMENTATION BE USED IN PROJECT IMPLEMENTATION UNTIL AFTER APPROVAL BY NASA SPACE TASK GROUP.

2\. DOCUMENTATION.-

2.1 Specifications.- The Contractor shall prepare the specifications indicated in the following paragraphs. Where specific missions dictate deviations to the requirements of individual specifications, an addendum shall be prepared, for the documents affected, which defines the changes for that mission. This is intended to present any configuration variations on a comparative basis to assure that full consideration is given to the basic objectives at all times, and to prevent compromise of these objectives.

2.1.1 Spacecraft Performance and Interface Specification.- This specification shall specify the performance requirements of the spacecraft. The specification shall define the general composition of the spacecraft, identify its major systems and modules, establish their functional relationships, and provide for their integration into the spacecraft.

2.1.2 Spacecraft-Module and Spacecraft-Adapter Performance and Interface Specifications.- These specifications, one for each module and the spacecraft adapter, shall define the external design load envelope, performance,

[redacted]

and general configuration parameters of the various spacecraft modules and the spacecraft adapter, and shall specify in detail the interface requirements of each module and the spacecraft adapter.

2.1.3 Ground-Support-Equipment Performance and Interface Specification.- This specification shall specify the general performance requirements for the spacecraft GSE. The specification shall define the major areas in which GSE is required and shall identify the major equipment required for

2.1.3.1 Launch, test, and checkout

2.1.3.2 Service, transport, and handling

2.1.3.3 Maintenance

2.1.3.4 Recovery

2.1.4 Spacecraft-Module and Spacecraft-Adapter Ground-Support-Equipment Performance and Interface Specifications.- These specifications, one for each spacecraft module and the spacecraft adapter, shall define the function, performance, and general configuration parameters of the various spacecraft modules and the spacecraft adapter GSE, and shall specify in detail the interface requirements of this GSE.

2.1.5 Environmental Criteria Specification.- This specification shall define the environmental criteria to be used for design, equipment selection, planning, and other purposes as applicable. Criteria for both the space and ground equipments shall be included. This specification shall be based upon Appendix D with additions as required to cover aspects of the environment not specified therein.

2.1.6 Design Criteria Specification.- This specification shall define the basic design criteria for the spacecraft and all ground equipment.

2.1.7 Life Sciences Criteria Specification.- The life sciences criteria to be used for purposes of design and general conduct of the program shall be defined in this specification. Included shall be man's

[redacted]

physiological and performance requirements and the human factor design standards to meet these requirements. This specification shall be based upon Appendix C with additions as required to cover aspects of the crew requirements not specified therein.

2.1.8 Ground Operational Support System Performance and Interface Specification.- This specification shall be prepared by the Contractor in close coordination with NASA Space Task Group and the other government agencies responsible for the ground operational support system, and shall specify the functional, performance, and special requirements of the ground operational support system. This specification shall identify the stations, equipments, and facilities required, and any modifications required to accomplish the necessary functions for the program. It shall establish requirements for the integration of all network elements and establish their functional relationship. It shall specify the interface requirements between this network and all other system elements and subsystems.

2.1.9 Ground Operational Support System Equipment Performance and Interface Specifications.- These specifications, one for each new equipment or each equipment requiring modifications, shall be prepared by the Contractor in close coordination with NASA Space Task Group and the other government agencies responsible for the ground operational support system; shall define the function, performance, and general configuration parameters; and shall specify in detail the interface requirements.

2.1.10 Spacecraft Subsystem Specifications.- The Contractor shall prepare subsystem and other equipment specifications which define the function, performance, and configuration, and include qualification, reliability and acceptance requirements.

2.1.11 Material, Parts, and Process Specifications.- The Contractor shall submit existing material, parts, and process specifications which will be used during Phase A. In cases where adequate materials and parts specifications do not exist, or are not suitable for the intended use, procurement specifications will be prepared by the Contractor. Where standards and process specifications covering items such as cleaning,

[redacted]

forming, heat treatment, etc., are not available or are not adequate, process specifications will be prepared by the Contractor.

2.2 Program Planning and Status.-

2.2.1 Program Planning Report.- This report shall be the basic document which describes the overall schedule plan for the development of the Apollo spacecraft. It shall include master phasing charts and milestone charts for the overall program and general management, technical, manufacturing, facilities, test, and support schedules. Anticipated critical schedule problems shall be identified and the intended method for their solution indicated. Subsidiary schedules for the development of major subsystems shall be included. Major actions and events required of all agencies affecting the development of the Apollo spacecraft shall be shown, including the government as well as major contractors and subcontractors. Changes shall be shown by revisions of the initial report in whole or in part, as necessary.

2.2.2 Facilities Planning Report.- This report shall cover the complete requirements for facilities development of the Apollo spacecraft and shall identify those which are to be government furnished. Industrial, launch-base, range, landing-base, and all other facility requirements shall be described in detail, including any necessary modifications of existing facilities. Schedules showing required availability and modification dates and plans for accomplishing necessary design and construction shall be included. Work in this area may not proceed until this plan is approved by the NASA.

2.2.3 Monthly Financial Status Reports.- This report shall include total funds allocated, expenditures for the reporting period, cumulative expenditures to-date, total direct manhours allocated, direct manhours expended for the period, and cumulative direct hours to date. Manhour expenditures shall indicate reference to applicable personnel categories such as engineering, engineering support, manufacturing, etc. In addition, a breakdown of estimated costs to program completion shall be shown. A graphical summary shall show cumulative direct manhours and material cost

[redacted]

along with estimated direct manhours and material costs to completion. Changes in estimate or rates of expenditures which differ from previous reports shall be noted, referencing the specific items concerned.

2.2.4 Technical Progress Reports.-

2.2.4.1 Quarterly Technical Progress Reports.- This report shall cover progress and status of the development of the Apollo spacecraft including management and major technical aspects, facilities, and other similar items. Major problems encountered and the solutions undertaken, or planned, shall be included. Any situation requiring NASA action or assistance shall be highlighted. Progress and status in relation to the master phasing and milestone schedules and any actual or anticipated changes thereto shall be shown, either in chart form or by data sufficient to show this information on the charts previously submitted.

2.2.4.2 Monthly Technical Progress Reports.- For those months for which quarterly technical progress reports are not required, a monthly technical progress report shall be furnished. This report shall consist primarily of statements describing the status of the overall program for the preceding month. Any significant events or problems shall be identified as will the need for any necessary action or assistance by the NASA.

2.2.4.3 Weekly Launch Site Activities Reports.- This report shall cover the status of the launch site activities relative to the preparation of the spacecraft.

2.2.4.4 Monthly Weight and Balance Reports.- The Contractor shall prepare weight and balance reports which provide continuing weight and balance information for all spacecraft equipment furnished by the Contractor.

2.2.5 Emergency Action Reports.- These reports shall be used by the Contractor for reporting any urgent matters which, unless solved immediately, could cause serious program delay. Such reports shall be forwarded by the most expeditious means available. Such urgent matters shall include

[redacted]

2.2.5.1 Strikes

2.2.5.2 Shortages of material and equipment in critical areas

2.2.5.3 Transportation tie-ups

2.2.5.4 Safety of flight problems

2.2.5.5 Critical development problems

2.2.5.6 Factors outside the Contractor's responsibility.

2.2.6 Still Photographs.- The Contractor shall provide "still photographs" showing major and critical system equipments and any significant events occurring during the period of the contract. All photographs so-furnished shall be 8" x 10" black-and-white, continuous-tone positive prints. The Contractor may provide color photographs in those instances where the Contractor believes that the importance of the subject matter requires such coverage.

2.2.7 Motion Picture Photography.- The Contractor shall provide 16-mm motion picture coverage with sound of all significant highlights of the program, within the area of his activity and responsibility, as the events occur. Edited positive film, which is capable of being used as a master, shall be furnished. All motion picture photography shall be in color except where technical reasons prevent the use of color film.

2.2.8 Reliability Plan.- The Contractor shall prepare with NASA assistance a reliability plan incorporating all elements of Mil-R-27542 (USAF) as guidelines. The plan will include those tasks specified in paragraph 3.4 but amplified to an extent commensurate with cost and schedule considerations.

2.2.9 Quarterly Reliability Status Report.- The Contractor shall prepare reliability status reports which provide a comprehensive view of the reliability program including the current demonstrated reliablity level for each major element and component, as defined in the reliability program plan; a discussion of reliability problems; failure analyses; and results of corrective action taken and corrective actions proposed.

[redacted]

2.2.10 Maintenance Plan.- The Contractor shall prepare a maintenance plan which describes the detailed requirements and procedures necessary to provide for the maintenance of all equipment throughout all phases of the program, in accordance with contractually-established maintenance concepts. The plan shall include maintenance during factory testing, storage, assembly, and prelaunch testing.

2.2.11 Support Plan.- The Contractor shall prepare a support plan which describes all required functions of equipment overhaul, material (spares) support, training, and transportation. Material support considerations shall include the methods of selection, distribution and control of spare parts, and the disposition of obsolete spare parts. Training considerations shall include training of ground operations and maintenance personnel, as well as training facilities, equipment, aids, and materials. Transportaton considerations shall include the total transportation requirements including spacecraft transportation, peculiar spare parts and GSE requiring transportation, and other pertinent transportation data. Packaging requirements shall be specified in the plan.

2.2.12 Test Plan.- The Contractor shall prepare a total test plan for the program. The plan shall cover all types of tests required under the contract including such items as engineering development tests, design verification tests, tests to determine operating environments or conditions, life sciences tests, qualification tests, acceptance tests, system compatibility tests, reliability demonstration tests, prelaunch tests, and flight tests. It shall outline the types and quantities of tests to be run, equipment and configurations to be tested, concepts and objectives of the tests, test locations, support requirements, and major time phasing.

2.2.13 Manufacturing Plan.- The Contractor shall prepare a manufacturing plan covering such items as manufacturing plans, schedules, methods, and controls.

2.3 Technical Data, Reports, and Analyses.- The Contractor shall prepare technical reports which describe the studies, analyses, and results of the contractual effort. The reports shall be prepared at times when complete blocks of work have been accomplished and, if appropriate, as logical subdivisions thereof. Major technical areas shall not be combined in a single document, but shall be published individually. The individual reports shall cover such technical specialties as trajectory analyses, stress analyses, life science studies, reliability analyses, spacecraft-module and spacecraft-adapter external loads analyses, failure-mode analyses, etc.

2.4 Spacecraft Launch Vehicle Integration Reports.- The Contractor, in cooperation with NASA, shall prepare a report for each of the launch vehicles to be used with the spacecraft, defining the performance, general characteristics, and interface characteristics of the launch vehicle assumed during design of the spacecraft.

2.5 Spacecraft Flight Reports.- A report showing the results of each flight test shall be submitted. Each such report shall consist of a detailed evaluation of the particular flight test and shall include the following types of information.

2.5.1 A section on the performance of each spacecraft subsystem together with an analysis of any malfunctions and the probable cause of the subject malfunction.

2.5.2 A section devoted to unexpected significant spacecraft difficulties, or results which were encountered during the flight test or preparations therefore, their bearing on future tests, and any corrective measures or product improvement proposed.

2.6 Qualification Reports and Data.-

2.6.1 Qualification Status List.- The Contractor shall prepare and maintain a status list showing the planned and completed qualification of each part, component, and subsystem for which he is responsible. The basis for qualification of those parts and components for which Apollo qualification tests are not required shall be shown. Where qualification is based on qualification tests conducted under the Apollo program, the date of such tests and reference to the detailed test reports shall be shown.

2.6.2 Qualification Test Reports and Data.- Data showing the results of all qualification tests shall be maintained and indexed in a master file by the Contractor. Reports shall be forwarded to the NASA Space Task Group showing the results of all qualification tests.

2.7 Acceptance Test Data.- Data showing the results of acceptance tests on major end items of ground support equipment and on major subsystems shall be prepared and furnished for review by the NASA Space Task Group. Acceptance test data on all other items shall be maintained by the Contractor and shall be made available for review by representatives of the NASA Space Task Group upon request.

2.8 Data and Reports on Other Tests.- Data showing the results of all required tests not otherwise provided for herein, which are the responsibility of the Contractor, shall be recorded and maintained on file. Reports shall be submitted on each of these tests or test series.

2.9 Detailed Test Procedures.- The Contractor shall prepare detailed test plans or procedures for all tests.

2.10 Spacecraft Equipment Status Report.- This report shall present a list of all spacecraft equipment indicating pertinent characteristics, qualification status, required qualification status, usage, reuseability, importance to spacecraft mission, and flight performance of each part.

2.11 Failure Data.- The Contractor shall prepare failure reports on all failures which occur on Contractor-furnished equipment during all phases of testing, operation, etc.

2.12 Drawings.- The Contractor shall maintain a complete up-to-date set of Contractor and Vendor drawings sufficient to describe each of the equipments for which he is responsible. These drawings shall be prepared using the Contractor's internal drawing system and shall conform to high quality commercial standards.

2.13 Handbooks, Manuals, and Field Instructions.- The Contractor shall prepare and provide manuals to define, in detail, operating and launch instructions as well as maintenance, checkout, and test procedures as indicated in the following paragraphs. The instructions and procedures contained in the manuals shall be arranged to permit operation, maintenance, checkout or test of the equipment covered by the appropriate manual in the minimum feasible amount of time. The material shall be designed to be readily understood by the personnel who will operate and/or maintain the equipment.

2.13.1 Checkout Manuals.- The checkout manuals shall provide the procedure and information required to perform checkout and tests of the appropriate systems. They shall permit complete checkout in the maintenance area or launch site.

2.13.2 Spacecraft Launch Operation Manuals.- Spacecraft launch operation manuals shall define the detailed procedures required to perform the tasks directly associated with the spacecraft prior to, including, and subsequent to launch. The manuals shall present, in sequential order, the instructions for tasks performed by members of the launch team who participate in the spacecraft launch operations.

2.13.3 Flight Operation Manual.- This operation manual shall provide the instructions and procedures to be followed by the spacecraft crew during all phases of the mission. The tasks to be performed by the spacecraft crew shall be presented in a logical sequence in individual sections pertinent to each phase of the mission.

2.13.4 Maintenance and Repair Manuals.- These manuals shall provide complete instructions and procedures for the maintenance and repair of the command module, service module, spacecraft adapter, and associated ground support equipment excluding the navigation and guidance systems and scientific instrumentation. A manual shall be provided for each major item of equipment or subsystem.

2.13.5 Spacecraft Familiarization Manual.- The spacecraft familiarization manual shall provide a description of the complete spacecraft. Each operational system shall be described in general terms but with sufficient detail to convey a clear understanding of the system as a whole. This manual shall cover the general spacecraft operational procedures and include a reference index of all operating and maintenance manuals. This manual shall serve as an orientation-indoctrination type document and as a reference document containing information relative to all systems and major components.

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2.13.6 Ground Support Equipment Manuals.- A manual shall be provided for each major item of command module, service module, and spacecraft adapter ground support equipment excluding the navigation and guidance system and scientific instrumentation ground support equipment. The manuals shall contain all the procedural instructions directly associated with, and required for, operation and checkout of the ground support equipment indicated above.

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TABLE 1. - MAJOR MILESTONES FOR PROJECT APOLLO SPACECRAFT

△ First flight of series

	MISSION	Calendar Year 1963	1964	1965	1966	1967
Phase A SATURN C-1	RESEARCH AND DEVELOPMENT SPACECRAFT	△				
	QUALIFICATION OF PROTOTYPE SPACECRAFT		△			
	MANNED EARTH-ORBITAL SPACECRAFT		△			
Phase B SATURN C-3	SUPER-ORBITAL REENTRY QUALIFICATION			△		
	MANNED CIRCUMLUNAR AND LUNAR ORBITAL			△		
Phase C NOVA	MANNED LUNAR LANDING AND RETURN					△

[redacted]

TABLE 2

PARTICLE DISTRIBUTION FOR THE HEART OF THE OUTER BELT

Particles	Energy MEV	Flux Particles/cm^2/sec
Electrons	.02	10^{11}
Electrons	.2	10^{8}
Electrons	2.5	10^{6}
Protons	60	10^{2}
Protons	30	-

[redacted]

TABLE 3

WHIPPLE'S DISTRIBUTION FOR SPORADIC METEOROIDS

Visual magnitude	Mass Slugs	Mass grams	Diameter* microns	Diameter* inches	Daily accretion of earth	Velocity km/sec	Velocity ft/sec
0	$1.71\mathrm{x}10^{-3}$	25.0	23,900	.940	$1.00\mathrm{x}10^{6}$	28	91,900
1	$6.82\mathrm{x}10^{-4}$	9.95	17,600	.693	$3.72\mathrm{x}10^{6}$	28	91,900
2	$2.71\mathrm{x}10^{-4}$	3.96	12,900	.508	$1.38\mathrm{x}10^{7}$	28	91,900
3	$1.08\mathrm{x}10^{-4}$	1.58	9,526	.374	$3.69\mathrm{x}10^{7}$	28	91,900
4	$4.30\mathrm{x}10^{-5}$	0.628	6,998	.275	$9.26\mathrm{x}10^{7}$	28	91,900
5	$1.71\mathrm{x}10^{-5}$	0.250	5,152	.203	$2.33\mathrm{x}10^{8}$	28	91,900
6	$6.82\mathrm{x}10^{-6}$	$9.95\mathrm{x}10^{-2}$	3,791	.149	$5.84\mathrm{x}10^{8}$	28	91,900
7	$2.71\mathrm{x}10^{-6}$	$3.96\mathrm{x}10^{-2}$	2,790	.110	$1.47\mathrm{x}10^{9}$	28	91,900
8	$1.08\mathrm{x}10^{-6}$	$1.58\mathrm{x}10^{-2}$	2,051	$8.07\mathrm{x}10^{-2}$	$3.69\mathrm{x}10^{9}$	27	88,600
9	$4.30\mathrm{x}10^{-7}$	$6.28\mathrm{x}10^{-3}$	1,511	$5.96\mathrm{x}10^{-2}$	$9.26\mathrm{x}10^{9}$	26	85,300
10	$1.71\mathrm{x}10^{-7}$	$2.50\mathrm{x}10^{-3}$	1,113	$4.37\mathrm{x}10^{-2}$	$2.33\mathrm{x}10^{10}$	25	82,000
11	$6.82\mathrm{x}10^{-8}$	$9.95\mathrm{x}10^{-4}$	816	$3.21\mathrm{x}10^{-2}$	$5.84\mathrm{x}10^{10}$	24	78,700
12	$2.71\mathrm{x}10^{-8}$	$3.96\mathrm{x}10^{-4}$	603	$2.37\mathrm{x}10^{-2}$	$1.47\mathrm{x}10^{11}$	23	75,500
13	$1.08\mathrm{x}10^{-8}$	$1.58\mathrm{x}10^{-4}$	442	$1.74\mathrm{x}10^{-2}$	$3.69\mathrm{x}10^{11}$	22	72,200
14	$4.30\mathrm{x}10^{-9}$	$6.28\mathrm{x}10^{-5}$	325	$1.28\mathrm{x}10^{-2}$	$9.26\mathrm{x}10^{11}$	21	68,900
15	$1.71\mathrm{x}10^{-9}$	$2.50\mathrm{x}10^{-5}$	215	$9.40\mathrm{x}10^{-3}$	$2.33\mathrm{x}10^{12}$	20	65,600
16	$6.82\mathrm{x}10^{-10}$	$9.95\mathrm{x}10^{-6}$	176	$6.93\mathrm{x}10^{-3}$	$5.84\mathrm{x}10^{12}$	19	62,300
17	$2.71\mathrm{x}10^{-10}$	$3.96\mathrm{x}10^{-6}$	129	$5.08\mathrm{x}10^{-3}$	$1.47\mathrm{x}10^{13}$	18	59,100
18	$1.08\mathrm{x}10^{-10}$	$1.58\mathrm{x}10^{-6}$	95	$3.74\mathrm{x}10^{-3}$	$3.69\mathrm{x}10^{13}$	17	55,800
19	$4.30\mathrm{x}10^{-11}$	$6.28.10^{-7}$	70	$2.75\mathrm{x}10^{-3}$	$9.26\mathrm{x}10^{13}$	16	52,500
20	$1.71\mathrm{x}10^{-11}$	$2.50\mathrm{x}10^{-7}$	51.5	$2.03\mathrm{x}10^{-3}$	$2.33\mathrm{x}10^{14}$	15	49,200
21	$6.82\mathrm{x}10^{-12}$	$9.95\mathrm{x}10^{-8}$	37.9	$1.49\mathrm{x}10^{-3}$	$5.84\mathrm{x}10^{14}$	15	49,200
22	$2.71\mathrm{x}10^{-12}$	$3.96\mathrm{x}10^{-8}$	27.9	$1.10\mathrm{x}10^{-3}$	$1.47\mathrm{x}10^{15}$	15	49,200
23	$1.08\mathrm{x}10^{-12}$	$1.58\mathrm{x}10^{-8}$	19.4	$8.12\mathrm{x}10^{-4}$	$3.69\mathrm{x}10^{15}$	15	49,200
24	$4.30\mathrm{x}10^{-13}$	$6.28\mathrm{x}10^{-9}$	12.2	$5.95\mathrm{x}10^{-4}$	$9.26\mathrm{x}10^{15}$	15	49,200
25	$1.71\mathrm{x}10^{-13}$	$2.50\mathrm{x}10^{-9}$	7.68	$4.37\mathrm{x}10^{-4}$	$2.33\mathrm{x}10^{16}$	15	49,200
26	$6.82\mathrm{x}10^{-14}$	$9.95\mathrm{x}10^{-10}$	4.86	$3.21\mathrm{x}10^{-4}$	$5.84\mathrm{x}10^{16}$	15	49,200
27	$2.71\mathrm{x}10^{-14}$	$3.96\mathrm{x}10^{-10}$	3.06	$2.37\mathrm{x}10^{-4}$	$1.47\mathrm{x}10^{17}$	15	49,200
28	$1.08\mathrm{x}10^{-14}$	$1.58\mathrm{x}10^{-10}$	1.95	$1.74\mathrm{x}10^{-4}$	$3.69\mathrm{x}10^{17}$	15	49,200
29	$4.30\mathrm{x}10^{-15}$	$6.28\mathrm{x}10^{-11}$	1.22	$1.28\mathrm{x}10^{-4}$	$9.26.10^{17}$	15	49,200
30	$1.71\mathrm{x}10^{-15}$	$2.50\mathrm{x}10^{-11}$	.78	$9.38\mathrm{x}10^{-5}$	$2.33\mathrm{x}10^{18}$	15	49,200
31	$6.82\mathrm{x}10^{-16}$	$9.95\mathrm{x}10^{-12}$	.49	$6.87\mathrm{x}10^{-5}$	$5.84\mathrm{x}10^{18}$	15	49,200

*Diameter is based on ρ_m = 3.5 grams/cc

TABLE 4

INTERPLANETARY ATMOSPHERE

Equivalent pressure	Equivalent density	Composition
10^{-6} dynes/cm^2	10^{-16} grams/cm^3	Hydrogen atoms

[redacted]

TABLE 5

GEODETIC STATION LOCATION CORRECTION DATA

(Reference D-3)

Systems	Stations	Correction Δu Meters	Δv Meters	Δw Meters
Western Hemisphere Geodetic System	NAD	-23	+142	+196
	SAD	-303	+98	-315
	SAO SP59	+4	+299	+15
	Vanguard	-12	+235	+120
	σ	$\pm$26	$\pm$22	$\pm$22
Europe-Africa-Siberia-India Geodetic System	ED	-57	-37	-96
	Indian	+200	+782	+271
	Arc	-109	-70	-289
	SAO SP59	-150	-2	-33
	σ	$\pm$23	$\pm$29	$\pm$23
Japan-Korea-Manchuria Geodetic System	Tokyo	-89	+551	+710
	SAO SP59	-29	-209	-147
	σ	$\pm$40	$\pm$53	$\pm$40
Australia Geodetic System	Sidney	+198	+262	-21
	SAO SP59	+149	-83	+116
	σ (Estimated)	$\pm$75	$\pm$90	$\pm$35
Argentina Geodetic System	SAO SP59	-81	+131	+105
	σ (Estimated)	$\pm$180	$\pm$160	$\pm$160

[redacted]

[redacted]

TABLE 6

SUN, MOON, AND PLANETARY CONSTANTS

Planet	M_s/M_p	ω	f
Sun	1.	$3.00504355 \times 10^{-6}$	0
Mercury	6,120,000.		0
Venus	406,645.	Synchronous	0
Earth	332,488.		1/298.30
Mars	3,088,000.	7.0882232×10^{-5}	1/191.8
Jupiter	1,047.39	1.7734082×10^{-4}	1/15.2
Saturn	3,500.	1.7055335×10^{-4}	1/10.2
Uranus	22,869.	1.6135556×10^{-4}	1/14.
Neptune	18,889.	1.1140400×10^{-4}	1/58.5
Pluto	400,000.		

$$G = (6.668 \pm .0005) \times 10^{-8} \frac{cm^3}{sec^2 \text{ gram}}$$

$$M_e = (5.977 \pm .004) \times 10^{27} \text{ grams}$$

$$L_e = 86164.09054 \text{ seconds}$$

$$A_u = 149.6 \times 10^6 \text{ km}$$

$$\frac{M_e}{M_m} = 81.375$$

[redacted]

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TABLE 7

DOCUMENTATION TYPE AND DELIVERY SCHEDULE*

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	No. of Copies
2.1.1	Spacecraft Performance and Interface Specification	2	As required	I	50** 250***
2.1.2	Spacecraft-Module and Spacecraft-Adapter Performance and Interface Specifications	2	As required	I	50** 250***
2.1.3	Ground Support Equipment Performance and Interface Specification	2	As required	I	20** 20***
2.1.4	Spacecraft-Module and Spacecraft-Adapter Ground-Support-Equipment Performance and Interface Specifications	2	As required	I	20** 20***
2.1.5	Environmental Criteria Specification	1	As required	I	20** 50***
2.1.6	Design Criteria Specification	1	As required	I	20** 50***

*Initial delivery requirements are shown as time after date of contract, unless otherwise noted.
**Prior to NASA approval.
***Subsequent to NASA approval.

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Table 7 (Continued)

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	No. of Copies
2.1.7	Life Sciences Criteria Specification	1	As required	I	20** 50***
2.1.8	Ground Operational Support System Performance and Interface Specification	2	As required	I	50** 250***
2.1.9	Ground Operational Support System Equipment Performance and Interface Specifications	6	As required	I	20** 50***
2.1.10	Spacecraft Subsystem Specifications	6	As required	I	50** 250***
2.1.11	Material, Parts, and Process Specifications	As required	As required	II	20
2.2.1	Program Planning Report	2	As required	I	50** 200***
2.2.2	Facilities Planning Report	2	As required	I	30** 80***
2.2.3	Monthly Financial Status Reports	15 days after end of first month	15 days after end of each month	II	40

**Prior to NASA approval.
***Subsequent to NASA approval.

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Table 7 (Continued)

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	No. of Copies
2.2.4.1	Quarterly Technical Progress Reports	1 month after end of first calendar quarter	1 month after end of each calendar quarter	II	200
2.2.4.2	Monthly Technical Progress Letters	1 month after end of first month of first calendar quarter	1 month after end of month for first two months of each calendar quarter	II	200
2.2.4.3	Weekly Launch Site Activities Reports	2 days after end of first week	2 days after end of each week	II	200
2.2.4.4	Monthly Weight and Balance Reports	10 days after end of first month	10 days after end of each month	II	200
2.2.5	Emergency Action Reports	As required	As required	II	20
2.2.6	Still Photographs	5 days after exposure	-	II	5
2.2.7	Motion Picture Photography	15 days after exposure	-	II	2
2.2.8	Reliability Plan	2	As required	I	20** 40***

**Prior to NASA approval.
***Subsequent to NASA approval.

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Table 7 (Continued)

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	No. of Copies
2.2.9	Quarterly Reliability Status Report	1 month after end of first calendar quarter	1 month after end of each calendar quarter	II	40
2.2.10	Maintenance Plan	4	As required	I	20** 40***
2.2.11	Support Plan	4	As required	I	20** 40***
2.2.12	Test Plan	1	As required	I	20** 80***
2.2.13	Manufacturing Plan	1	As required	I	20** 40***
2.3	Technical Data, Reports and Analyses	As required	As required	II	20
2.4	Spacecraft Launch Vehicle Integration Report	4	As required	II	20
2.5	Spacecraft Flight Reports	1 month after each flight	-	I	500

**Prior to NASA approval.
***Subsequent to NASA approval.

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Table 7 (Continued)

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	No. of Copies
2.6.1	Qualification Status List	12	15 days	II	20
2.6.2	Qualification Test Reports and Data	15 days after each test series	-	II (Reports) III (Data)	20
2.7	Acceptance Test Data	15 days after each test series	-	II (Subsystem) III (All others)	20
2.8	Data and Reports on other Tests	15 days after each test series	-	II (Reports) III (Data)	20
2.9	Detailed Test Procedures	1 month prior to each test series	-	II	20
2.10	Spacecraft Equipment Status Report	12	15 days	II	100
2.11	Failure Data	5 days after failure	As required	II	2
2.12	Drawings	As released	As required	I II	1 3
2.13.1	Checkout Manuals	6	As required	I	20** 100**
2.13.2	Spacecraft Launch Operation Manuals	6	As required	I	20** 250***

**Prior to NASA approval.
***Subsequent to NASA approval.

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Table 7 (Continued)

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	No. of Copies
2.13.3	Flight Operation Manual	4	As required	I	40** 400***
2.13.4	Maintenance and Repair Manuals	6	As required	I	20** 250***
2.13.5	Spacecraft Familiarization Manual	6	As required	I	40** 500***
2.13.6	Ground Support Equipment Manuals	6	As required	I	20** 40***

**Prior to NASA approval.
***Subsequent to NASA approval.

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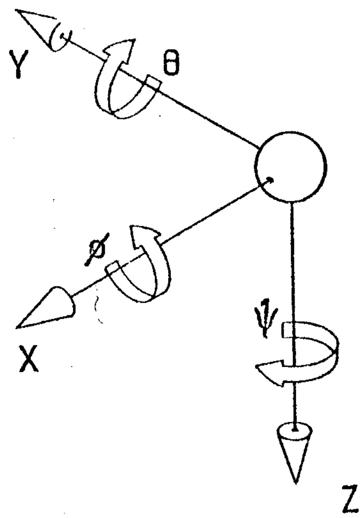
Positive directions of axes and angles (forces and moments) are shown by arrows.



Axis		Moment about axis		
Designation	Symbol	Designation	Symbol	Positive direction
Longitudinal	X	Rolling	L	Y⟶Z
Lateral	Y	Pitching	M	Z⟶X
Normal	Z	Yawing	N	X⟶Y

Force (parallel to axis) symbol	Angle		Velocities	
	Designation	Symbol	Linear (component along axis)	Angular
X	Roll	ϕ	u	p
Y	Pitch	θ	v	q
Z	Yaw	ψ	w	r

Figure 1.- Reference axis system.

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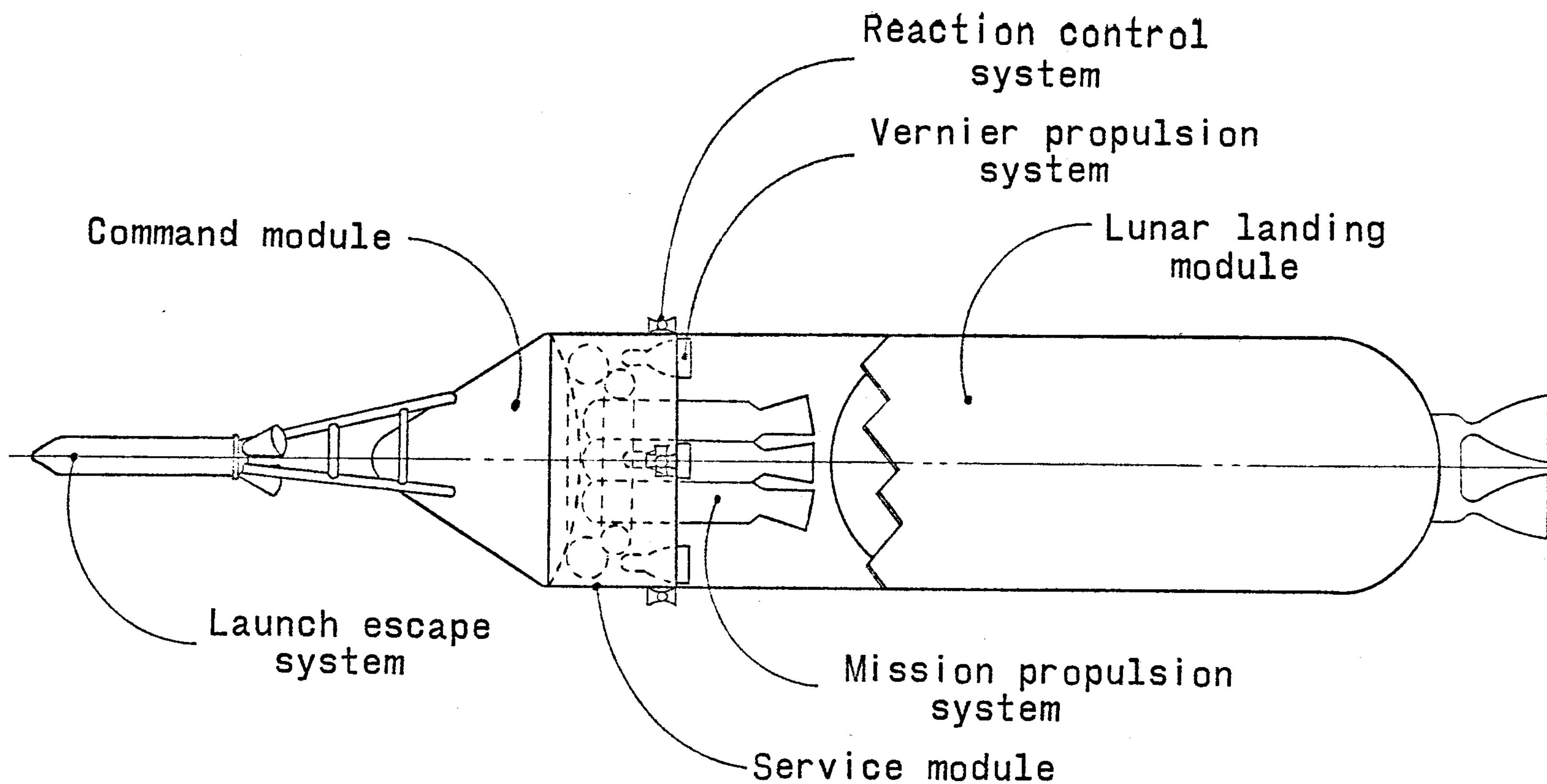

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Figure 2.- General arrangement - Lunar landing configuration.

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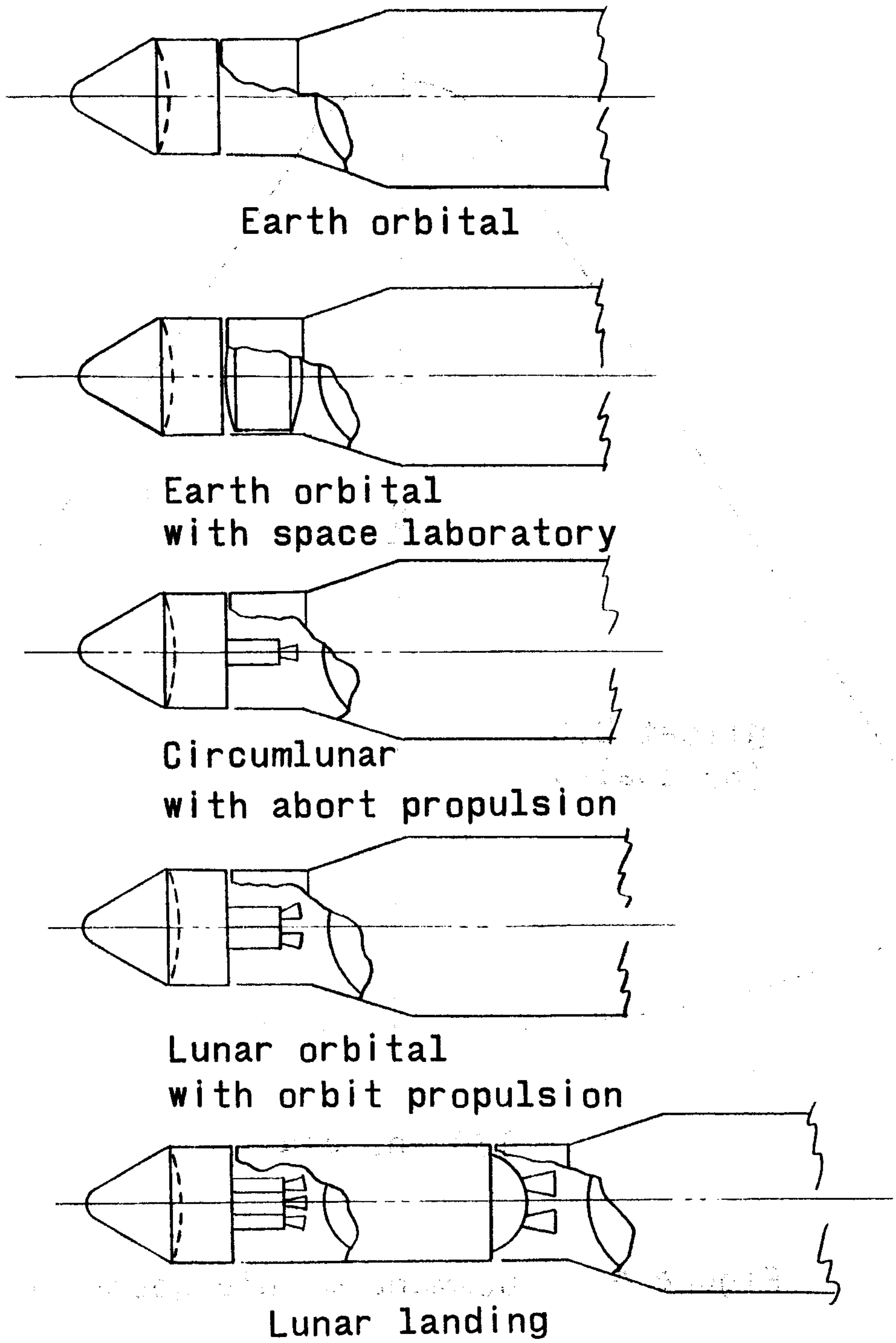

Figure 3.- Mission arrangements.

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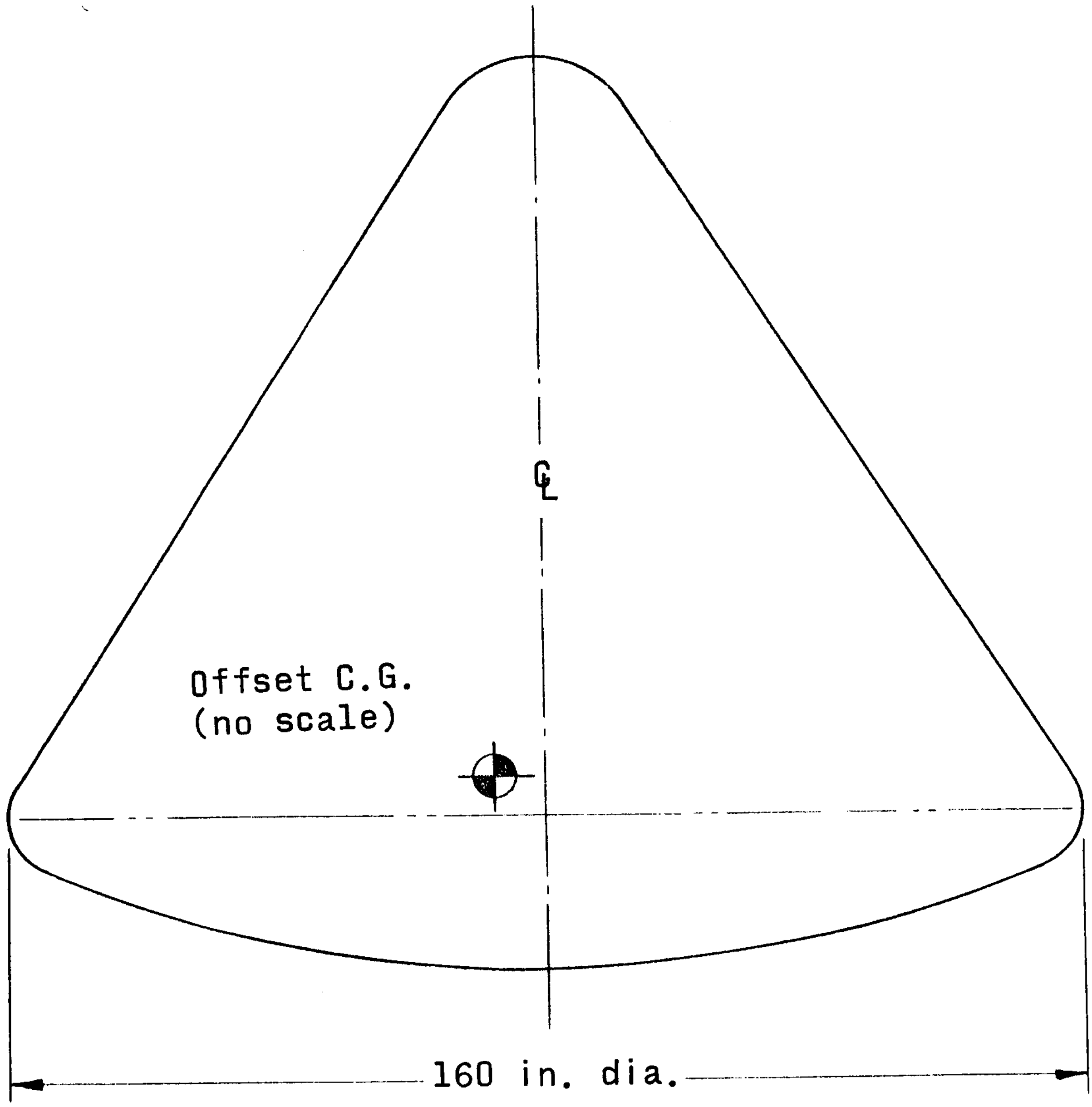

Figure 4.- Command module geometry.

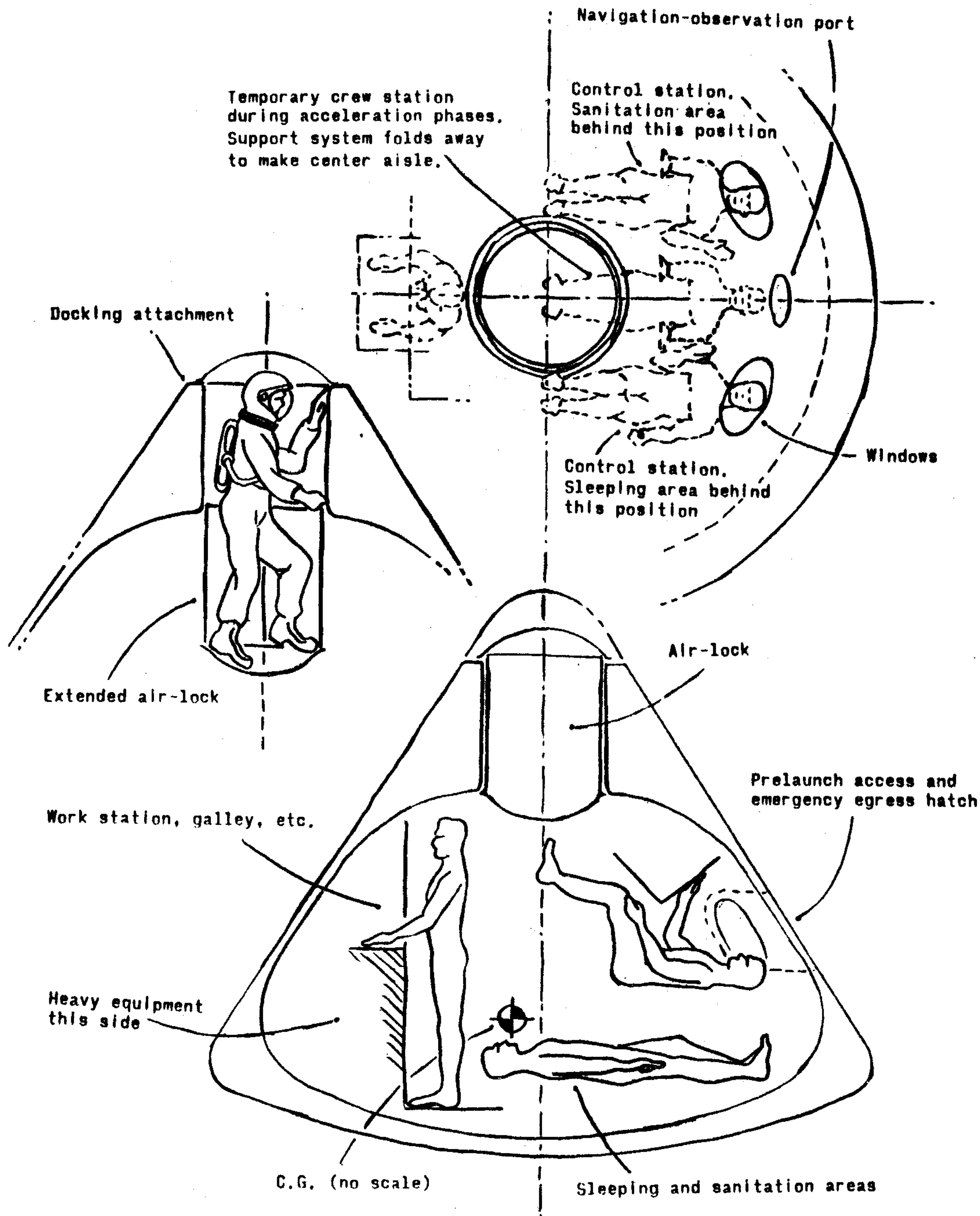

Figure 5.- Command module - inboard profile.

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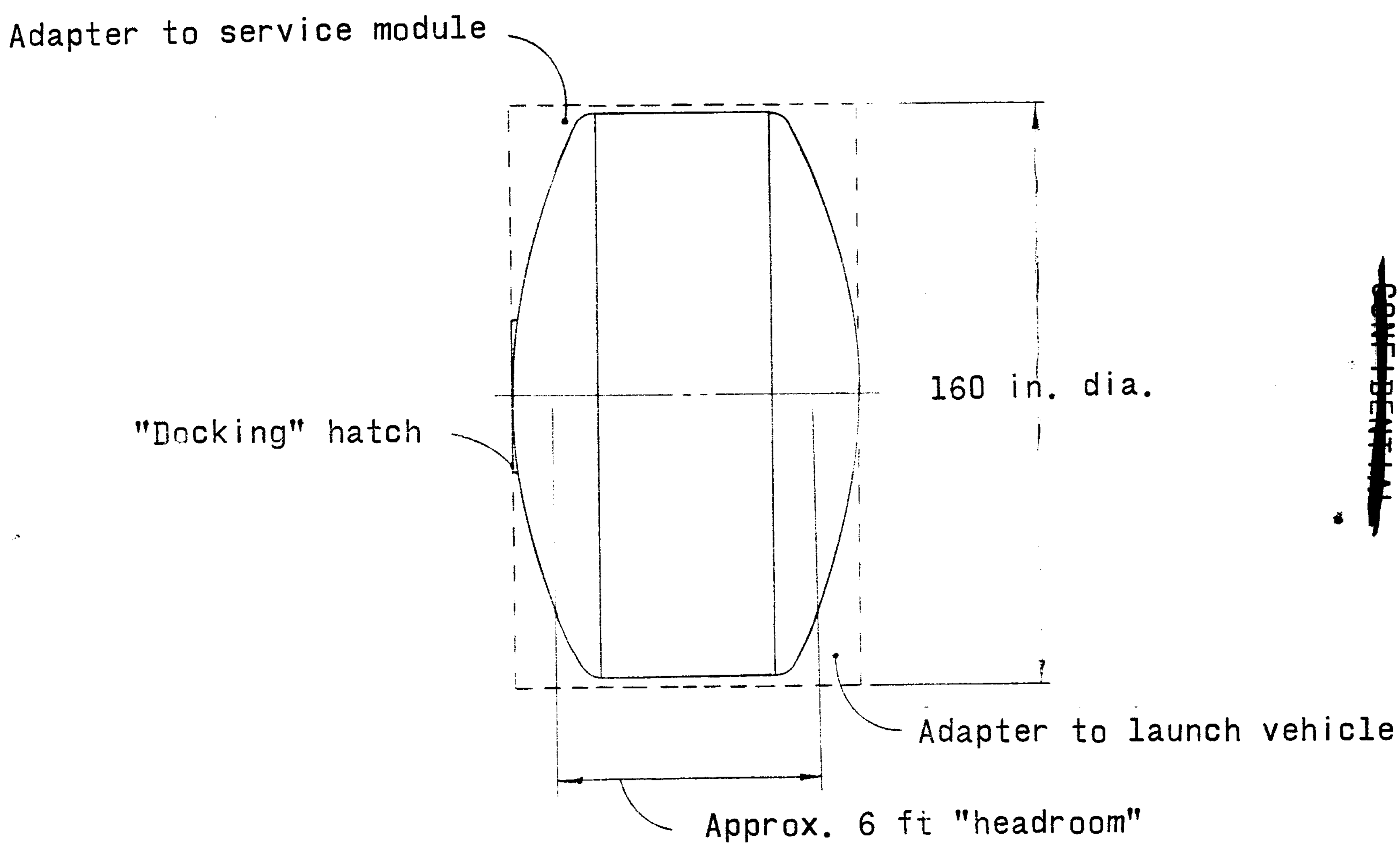

Figure 6.- Space laboratory module.

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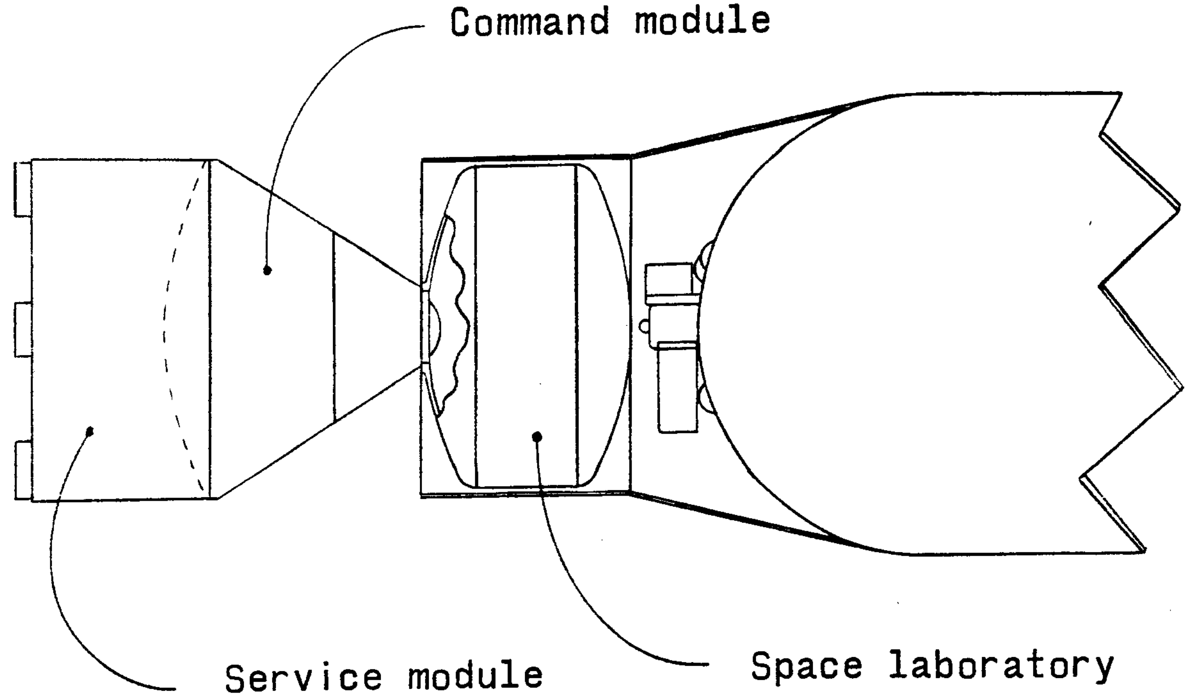

Figure 7.- Docking arrangement.

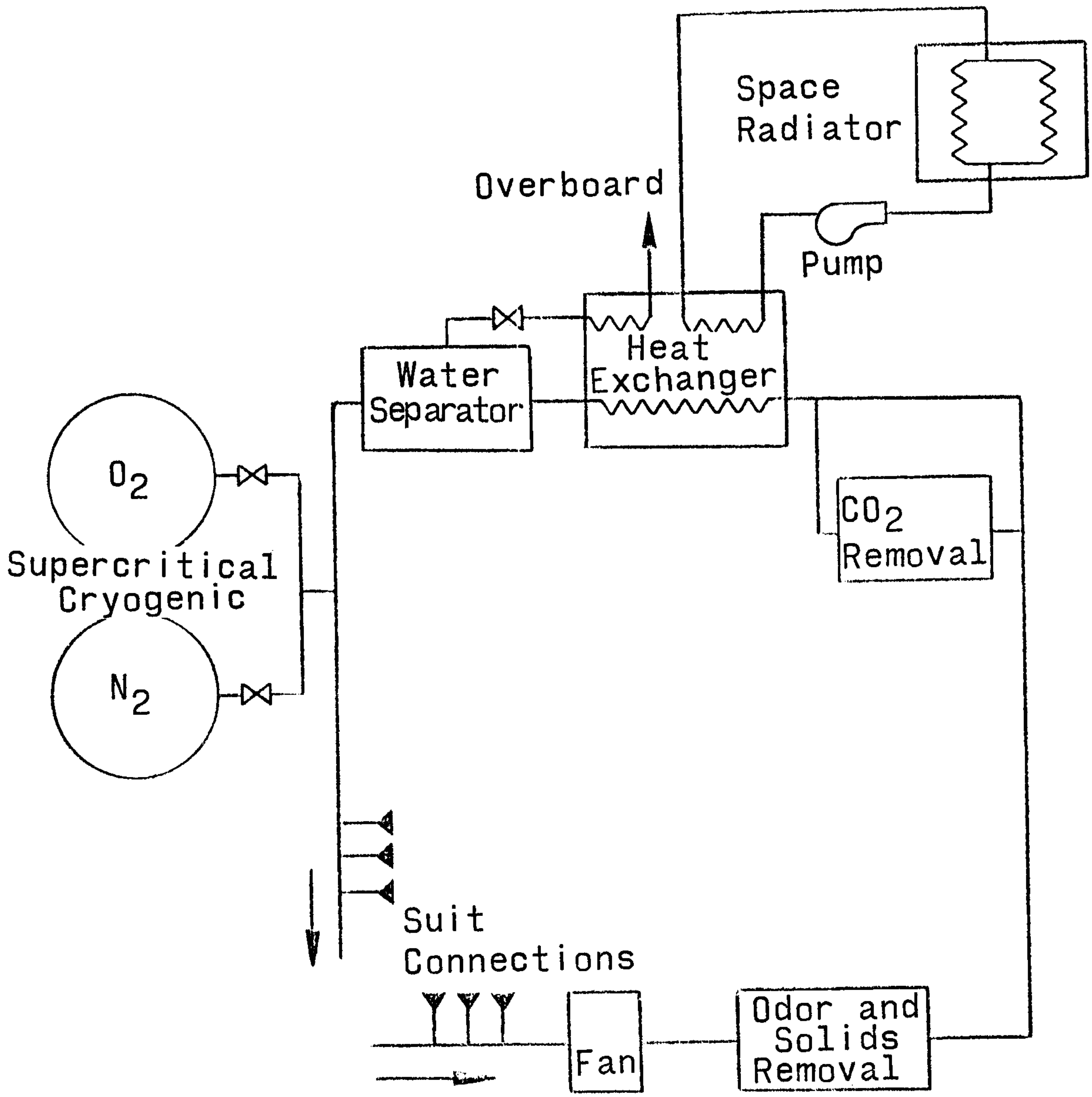

Figure 8.- Environmental control system.

[redacted]

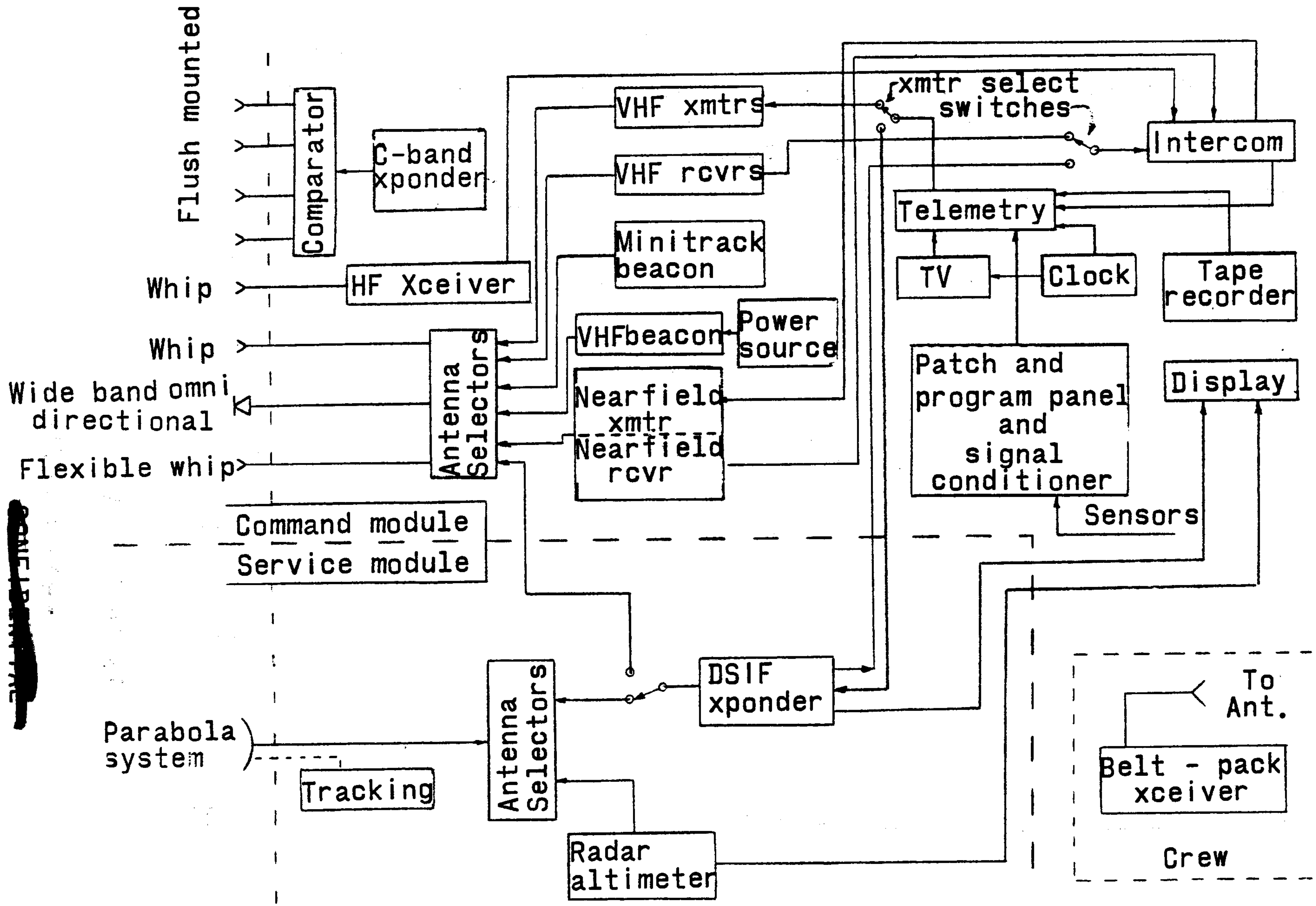

Figure 9.- Communication and instrumentation system diagram.

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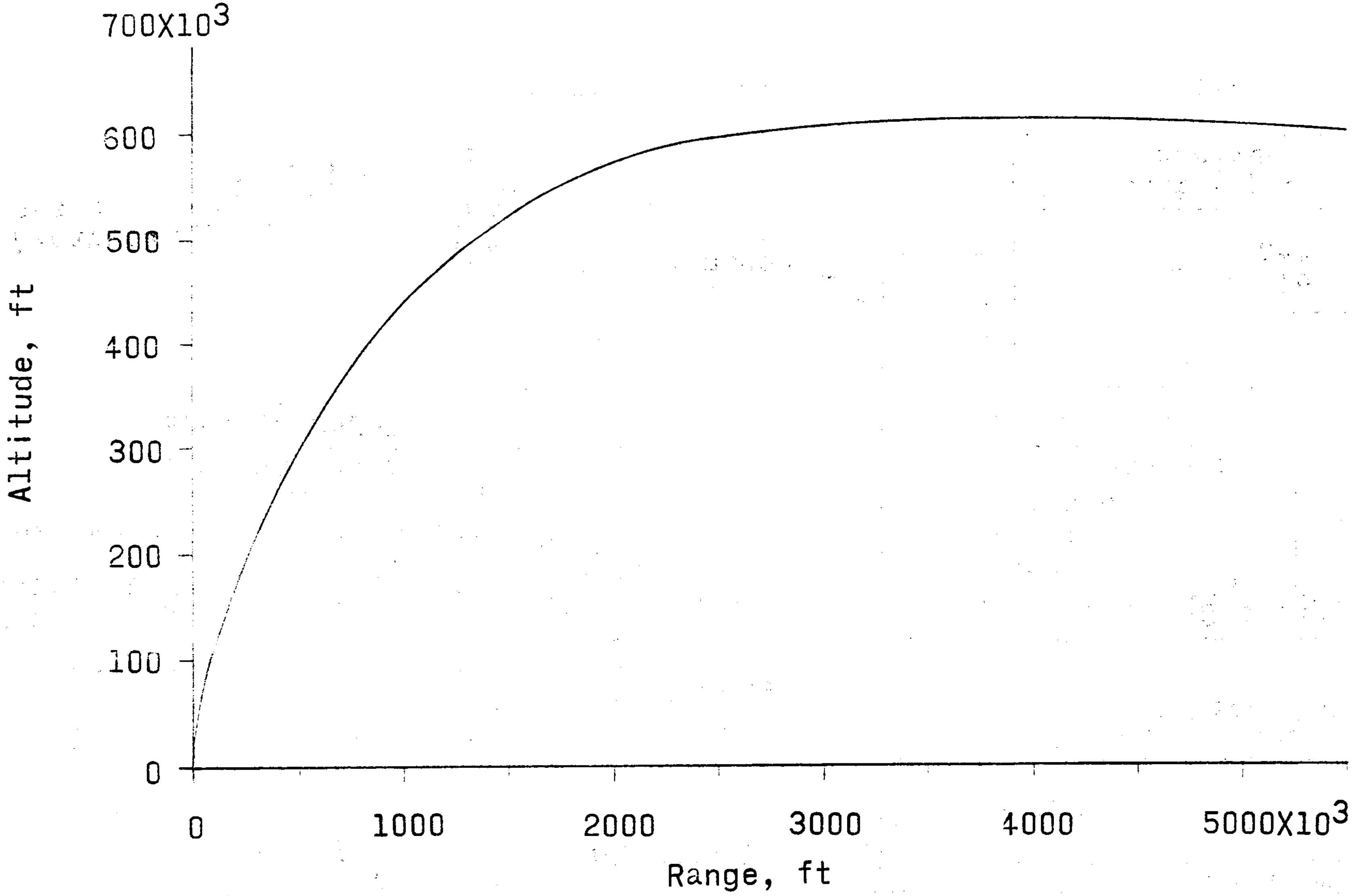

Figure 10.- Altitude vs Range from lift-off to parking orbit.
Launch Azimuth = 90^{o}.

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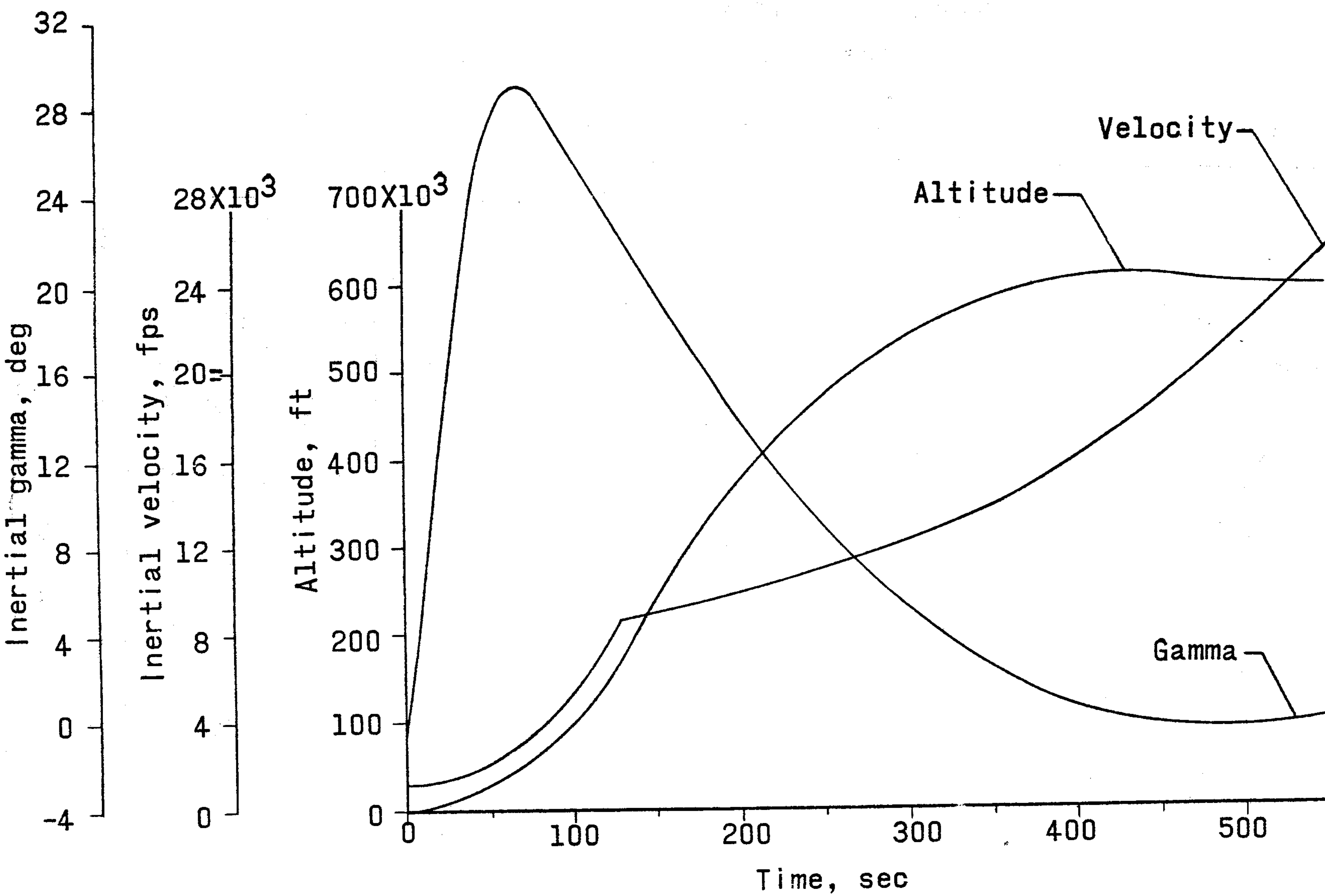
[redacted]



(a) Flight path.

Figure 11.- Time history from lift-off to parking orbit.

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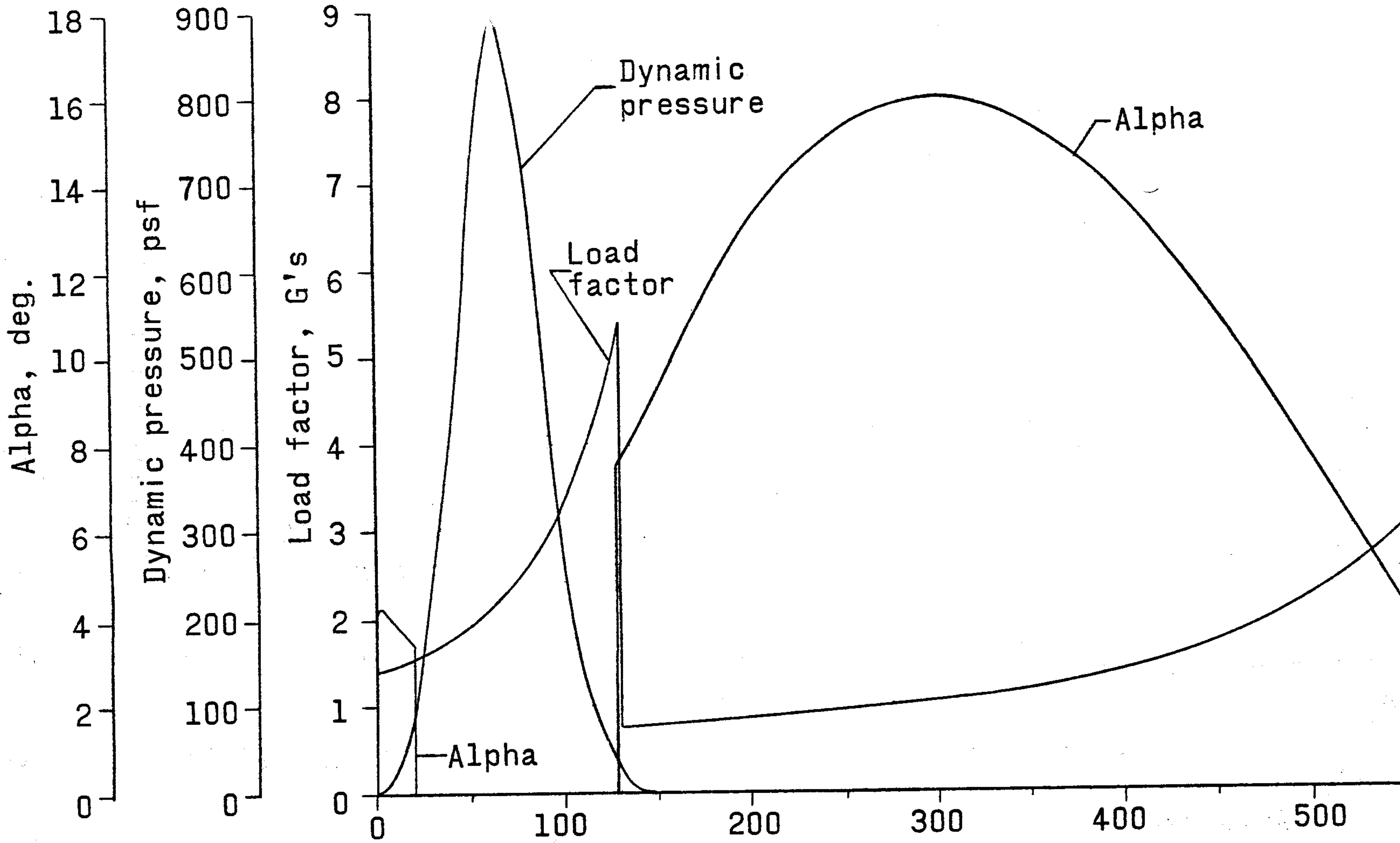

(b) Loads.

Figure 11.- Concluded.

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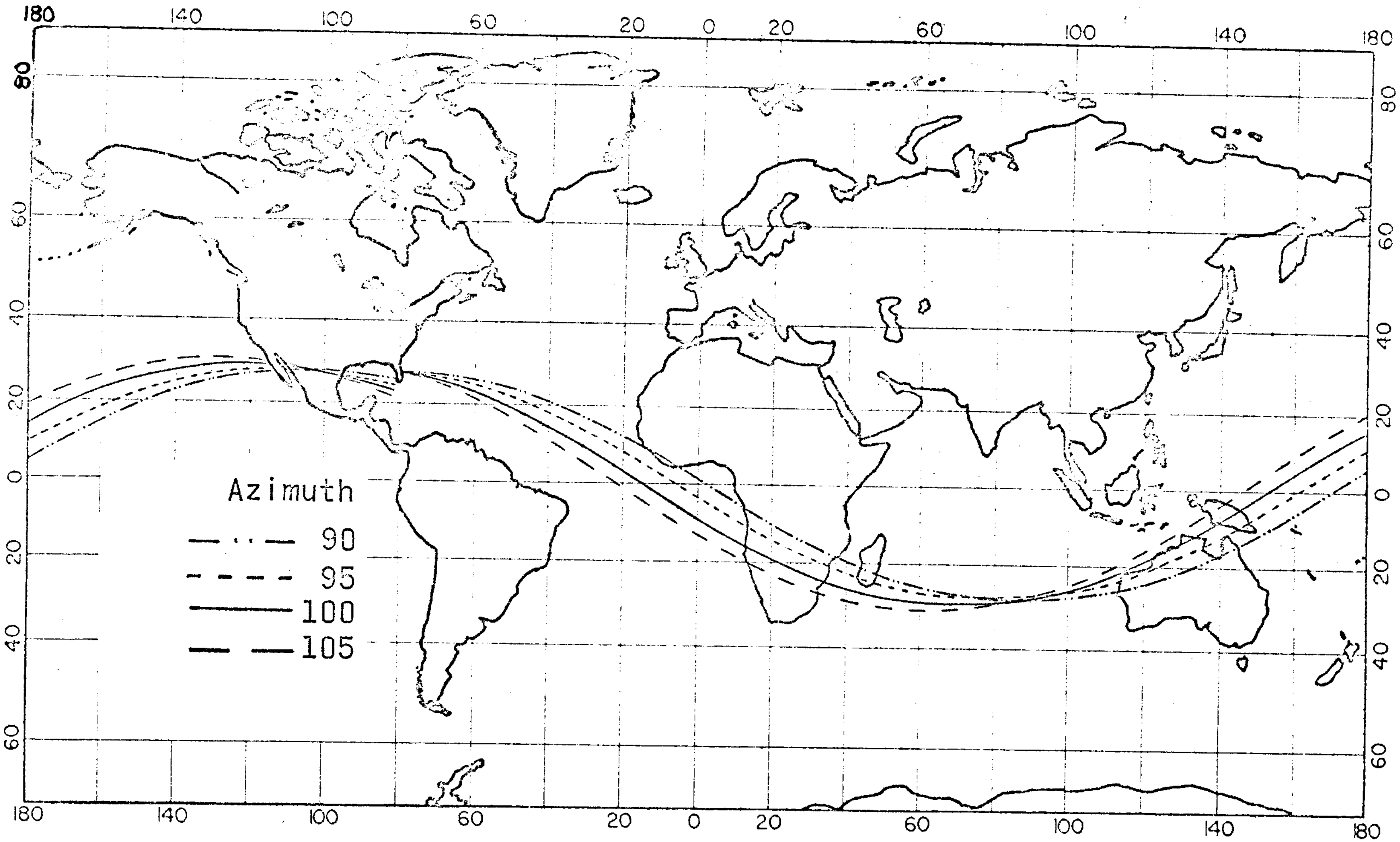

Figure 12.- Earth tracks for parking orbits for several launch azimuths.

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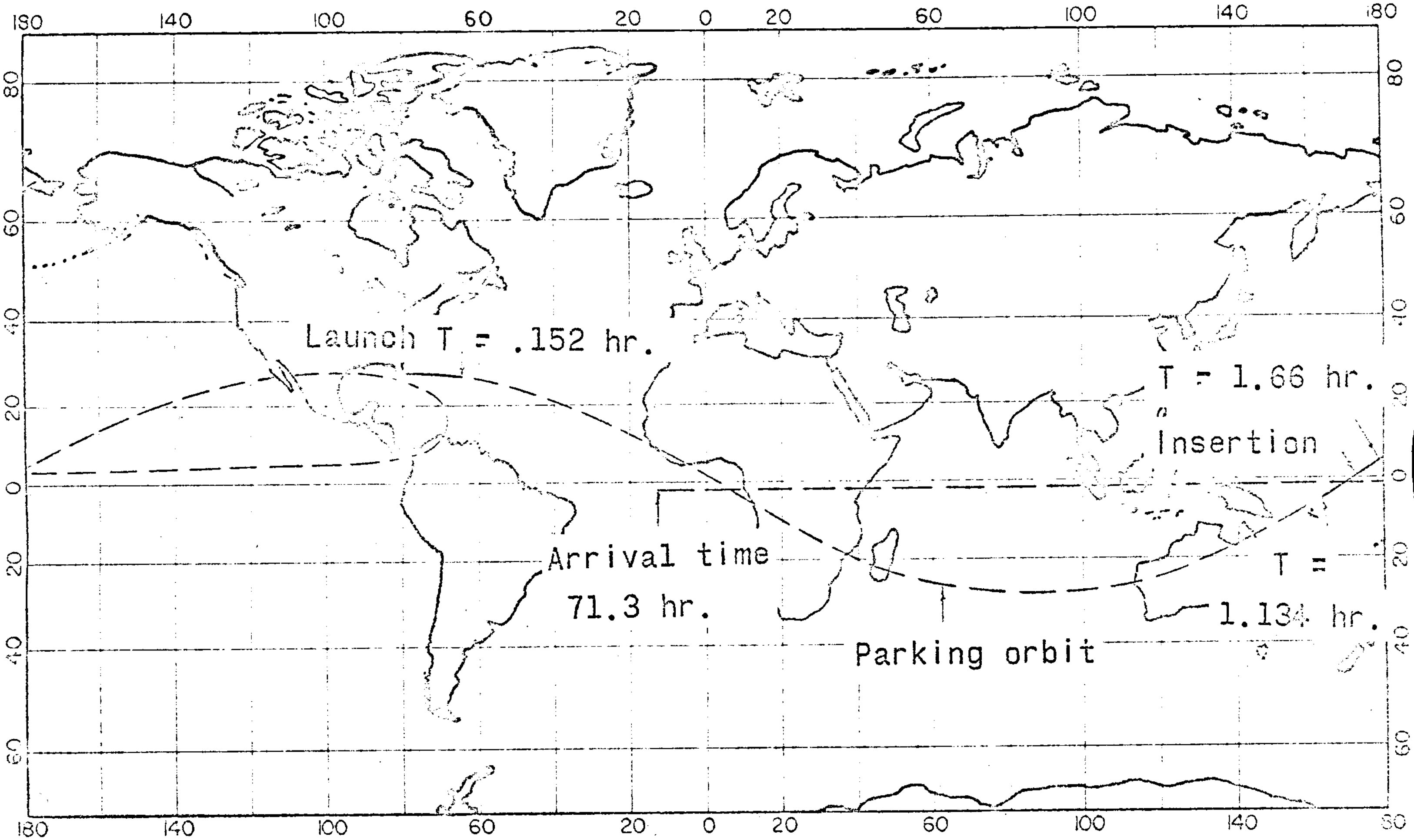

(a) Launch at noon.

Figure 13.- Earth tracks for phases of two lunar flight plans.

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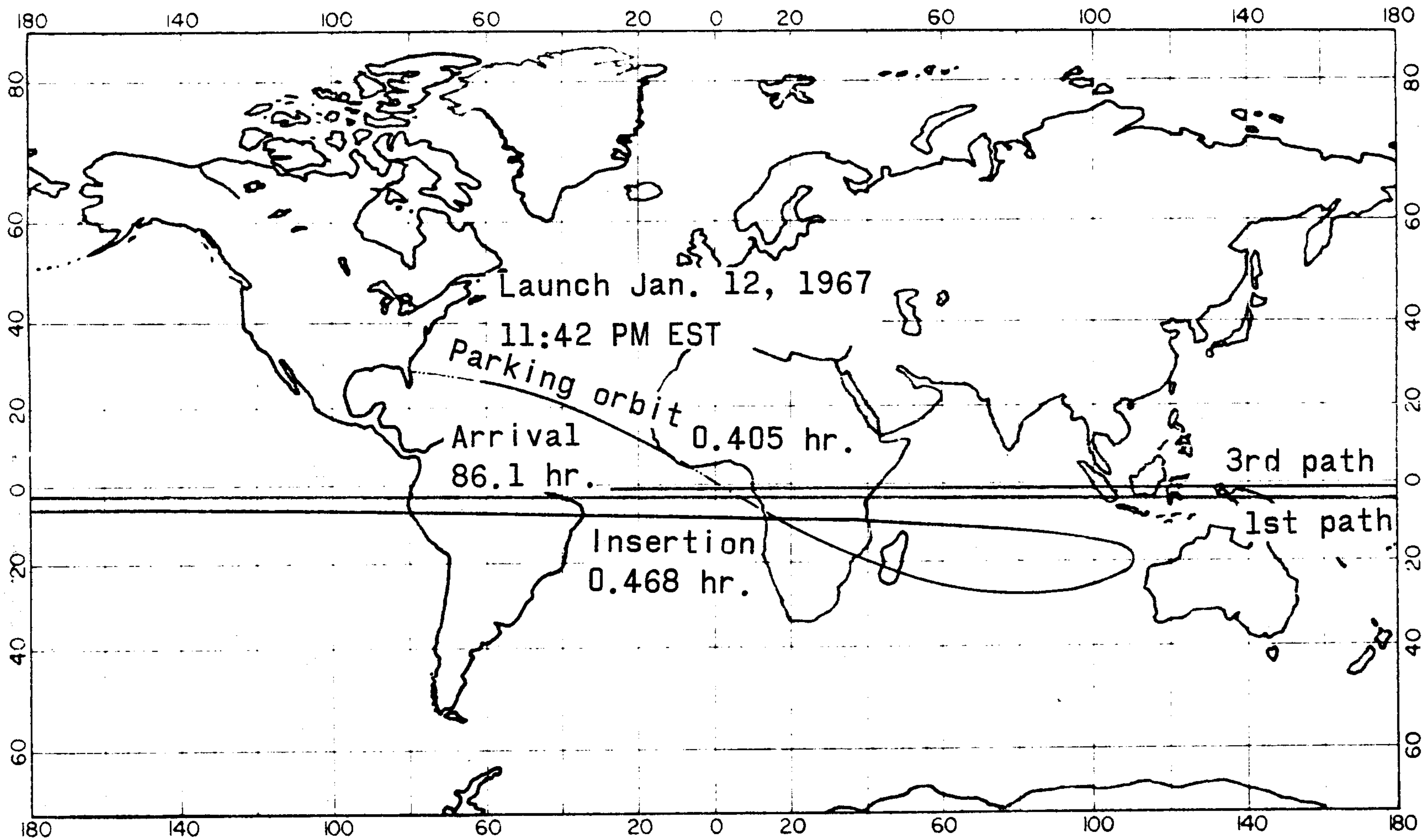

(b) Launch at midnight.

Figure 13.- Concluded.

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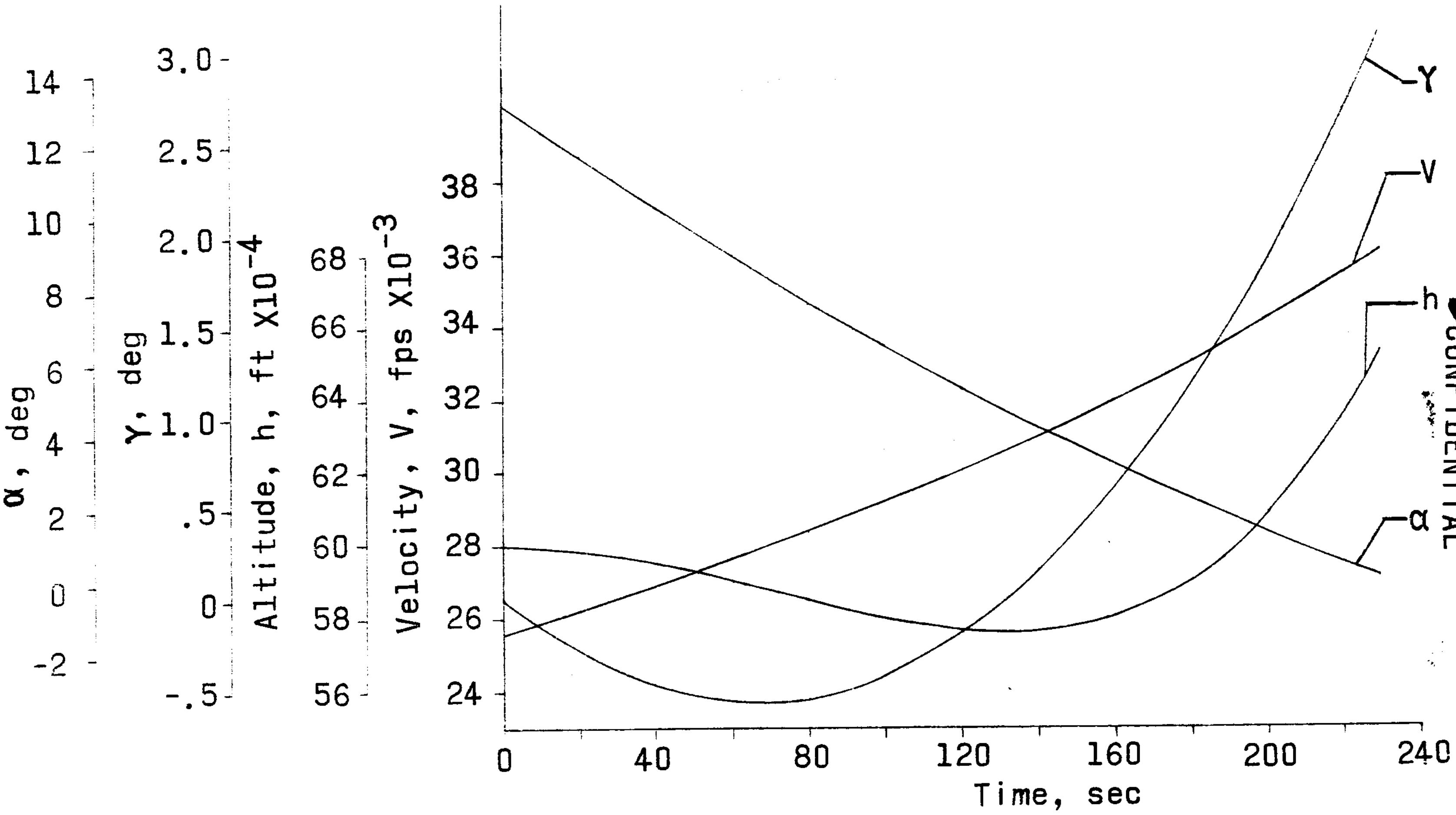

Figure 14.- Time history of transfer from parking orbit to translunar trajectory.

[redacted]

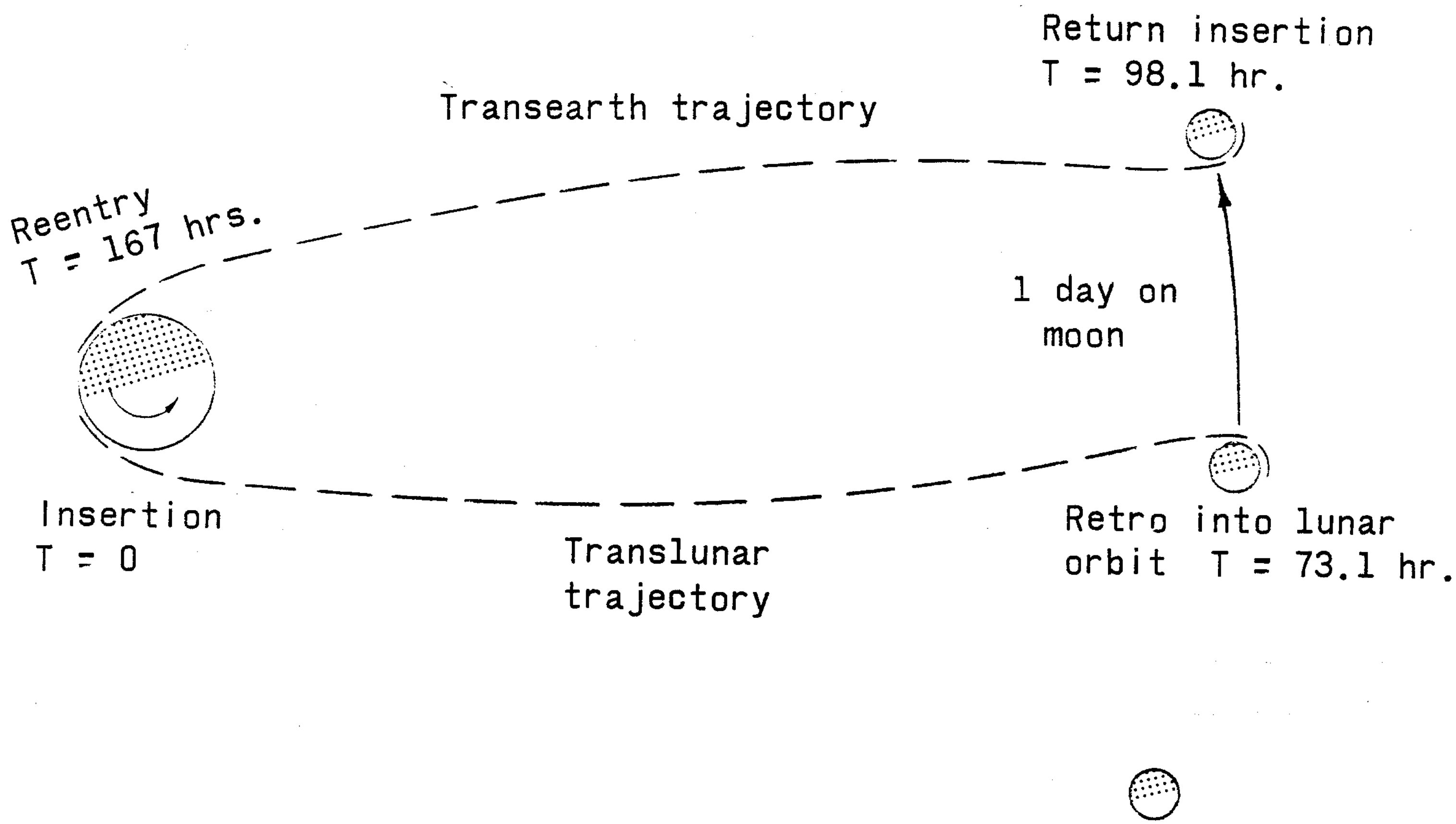

Figure 15.- Translunar and transearth trajectories shown in the inertial Earth-Moon system.

[redacted]

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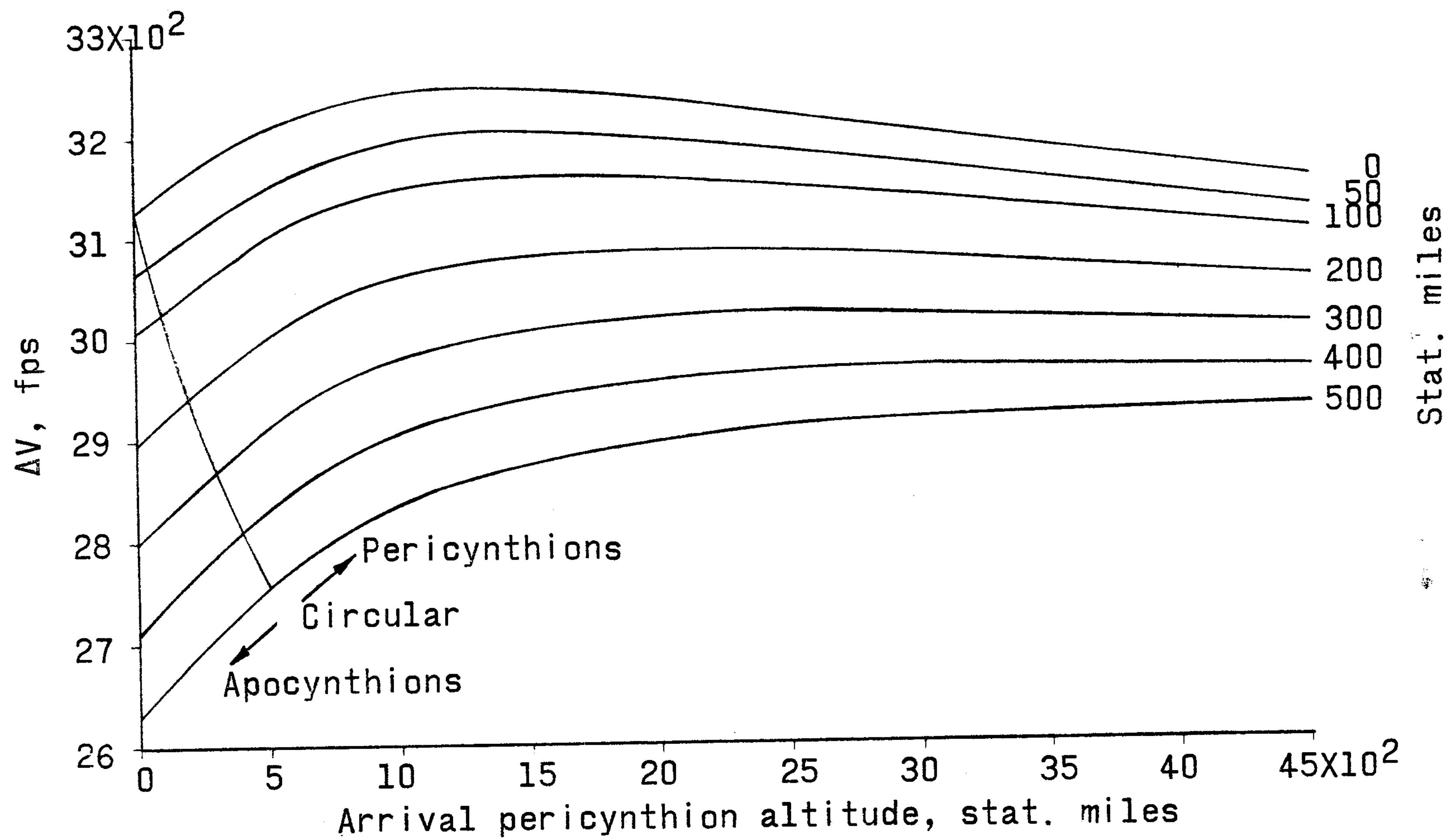

Figure 16.- Retro velocity requirements to establish local lunar orbits from earth returning circumlunar trajectories.

[redacted]

[redacted]

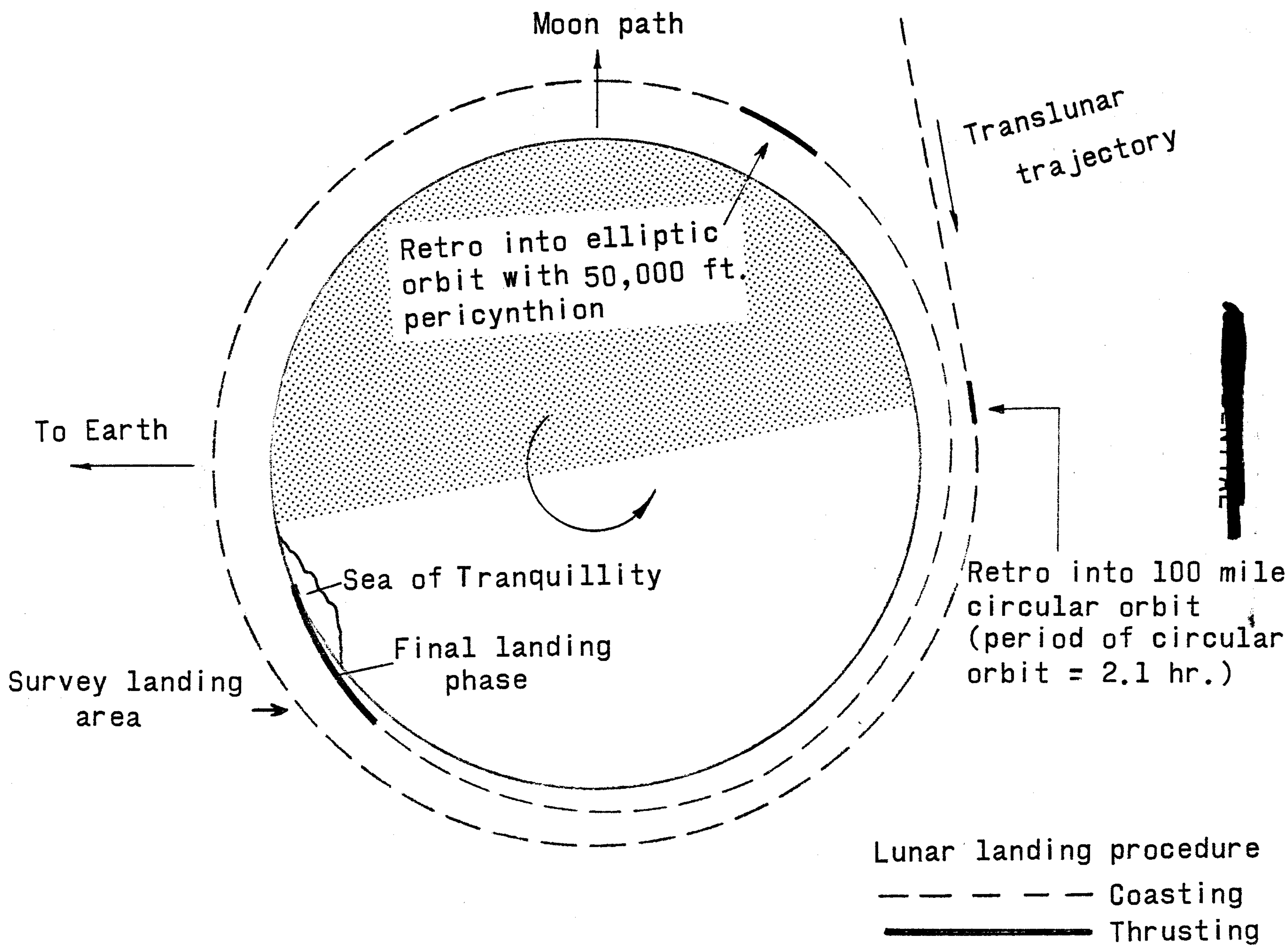

Figure 17.- Lunar landing technique.

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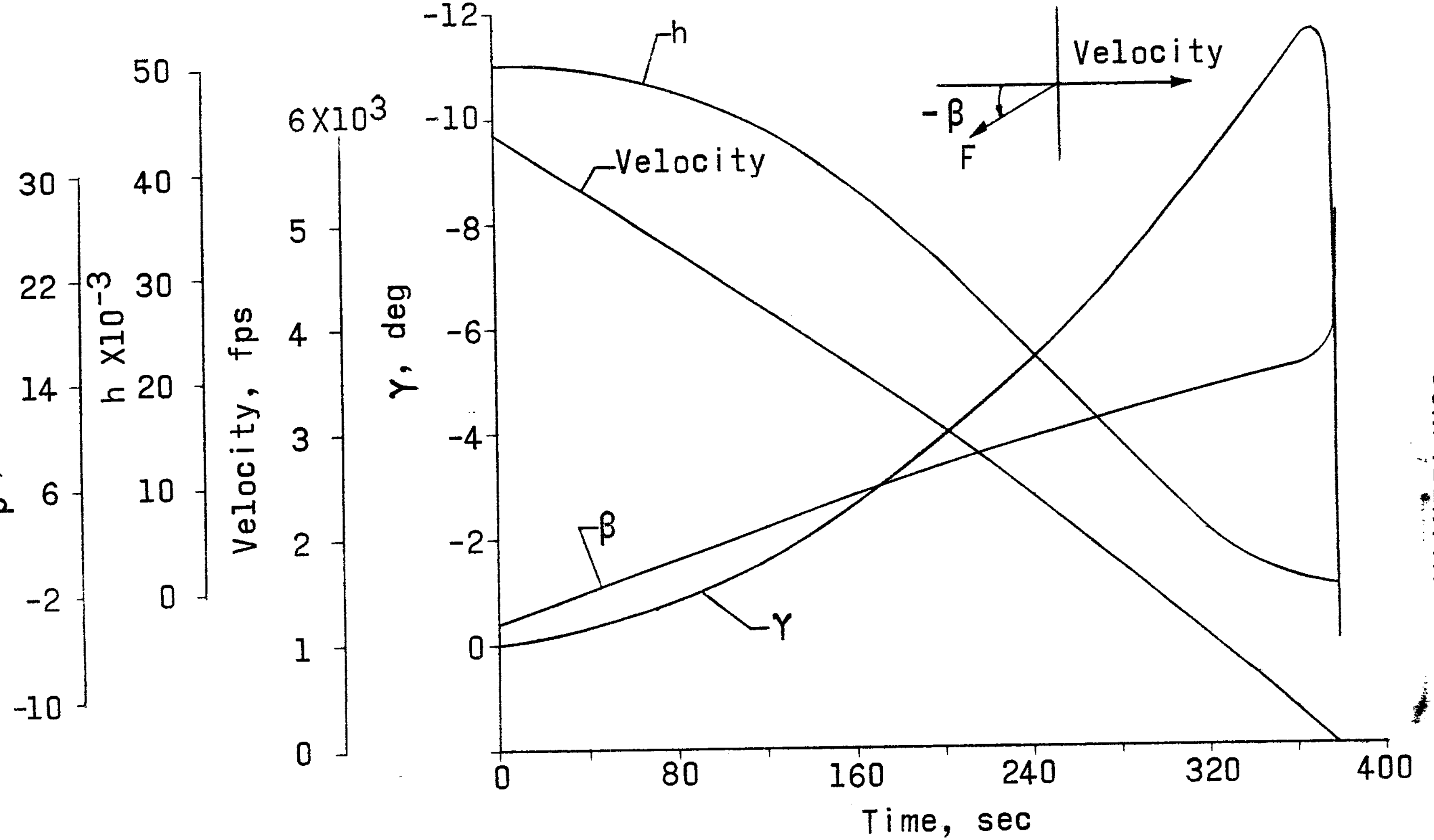

Figure 18.- Time history for a lunar landing from an elliptical orbit of perigee altitude of 50,000 ft.

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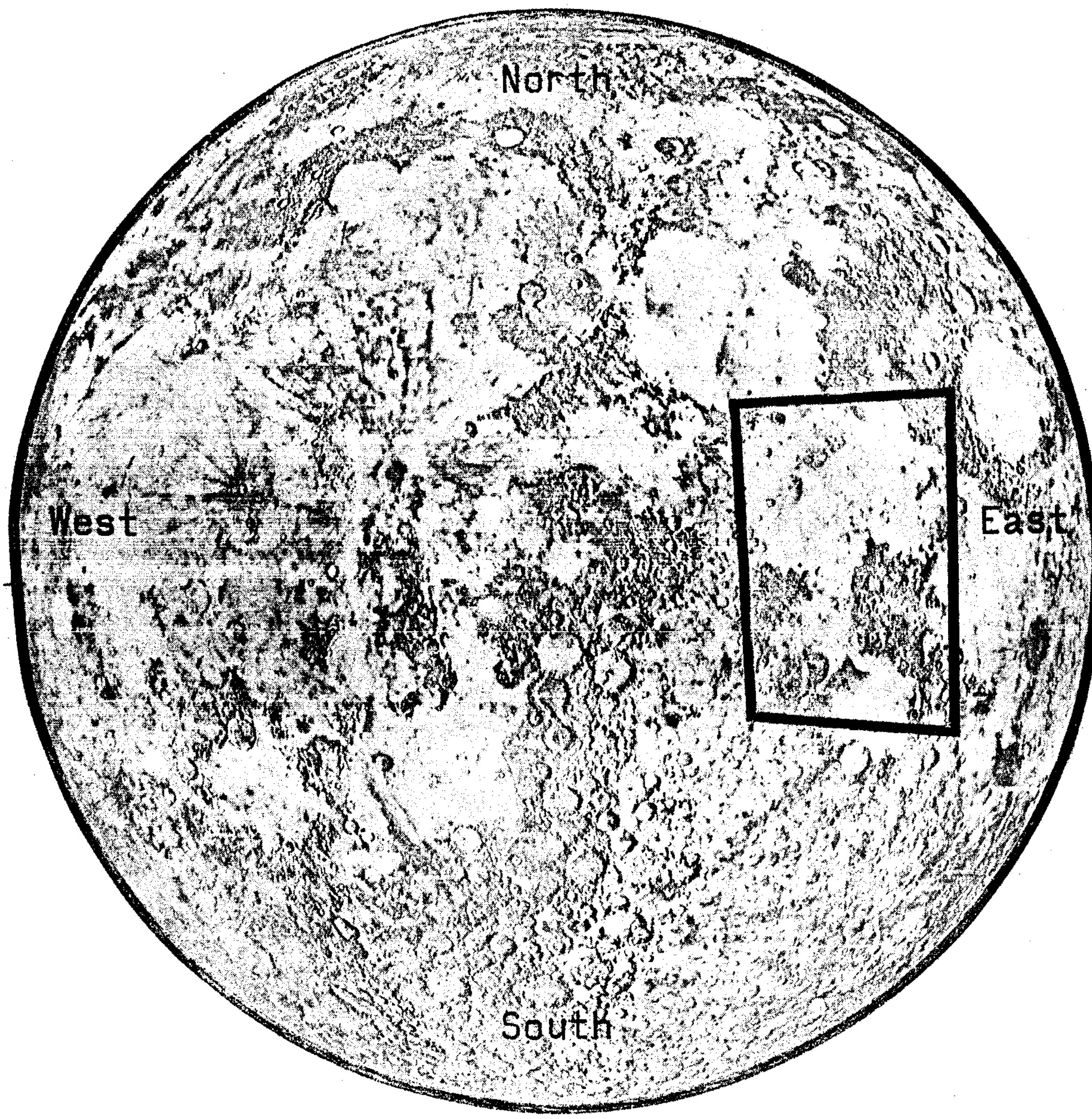

(a) Broad view.

Figure 19.- Photograph of moon showing proposed landing sites.

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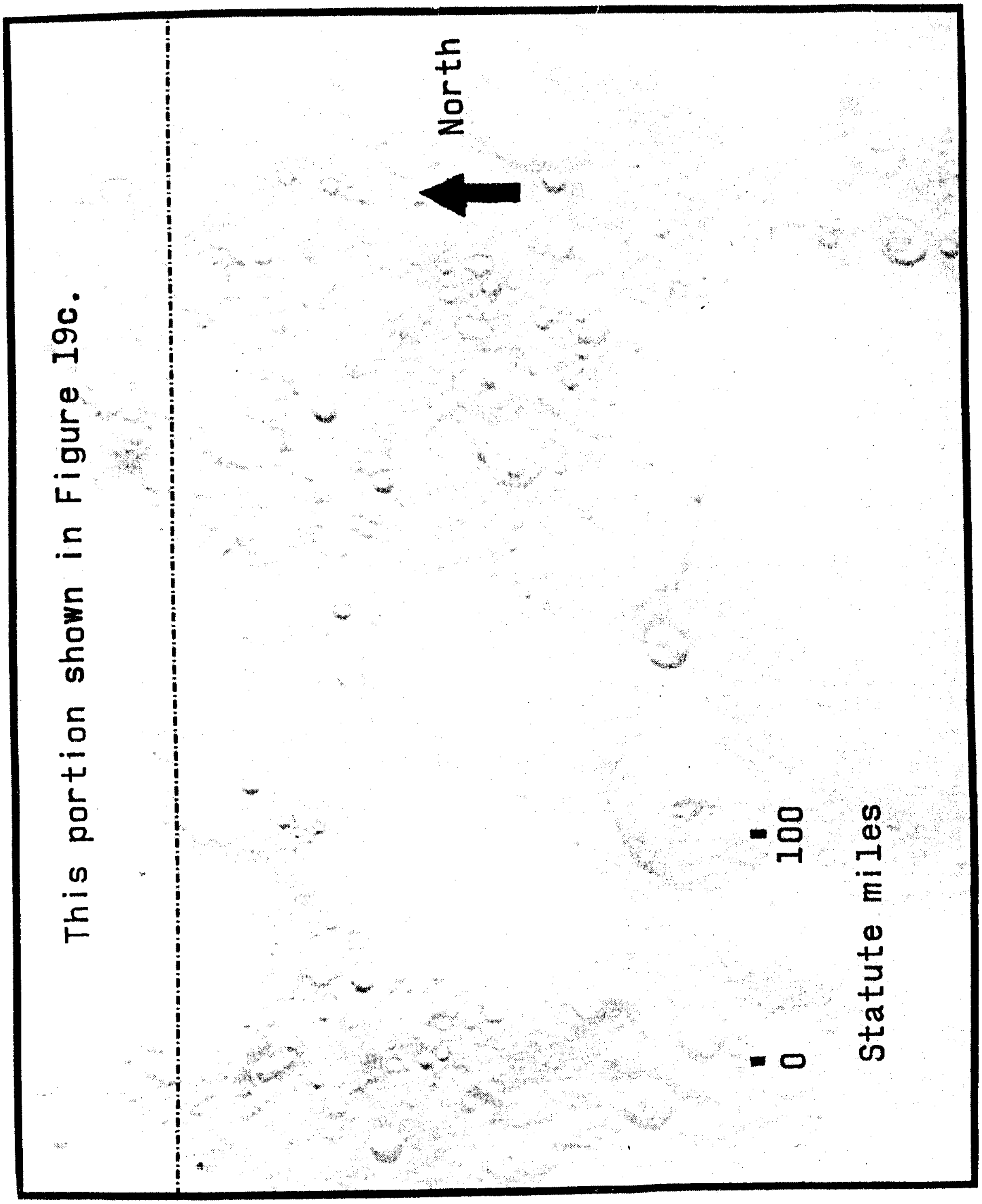

(b) Close-up.

Figure 19.- Continued.

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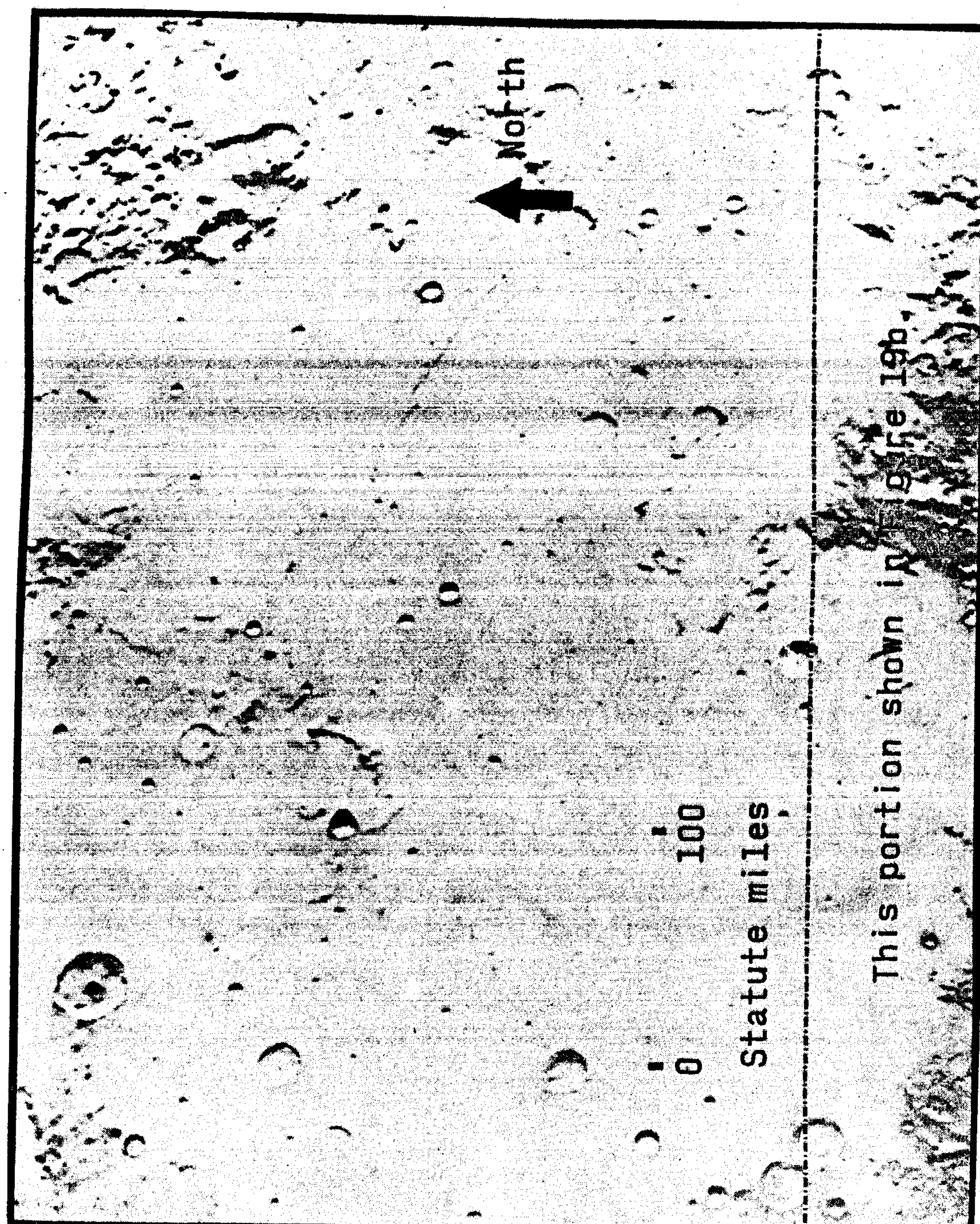

(c) Close-up.
Figure 19.- Concluded.

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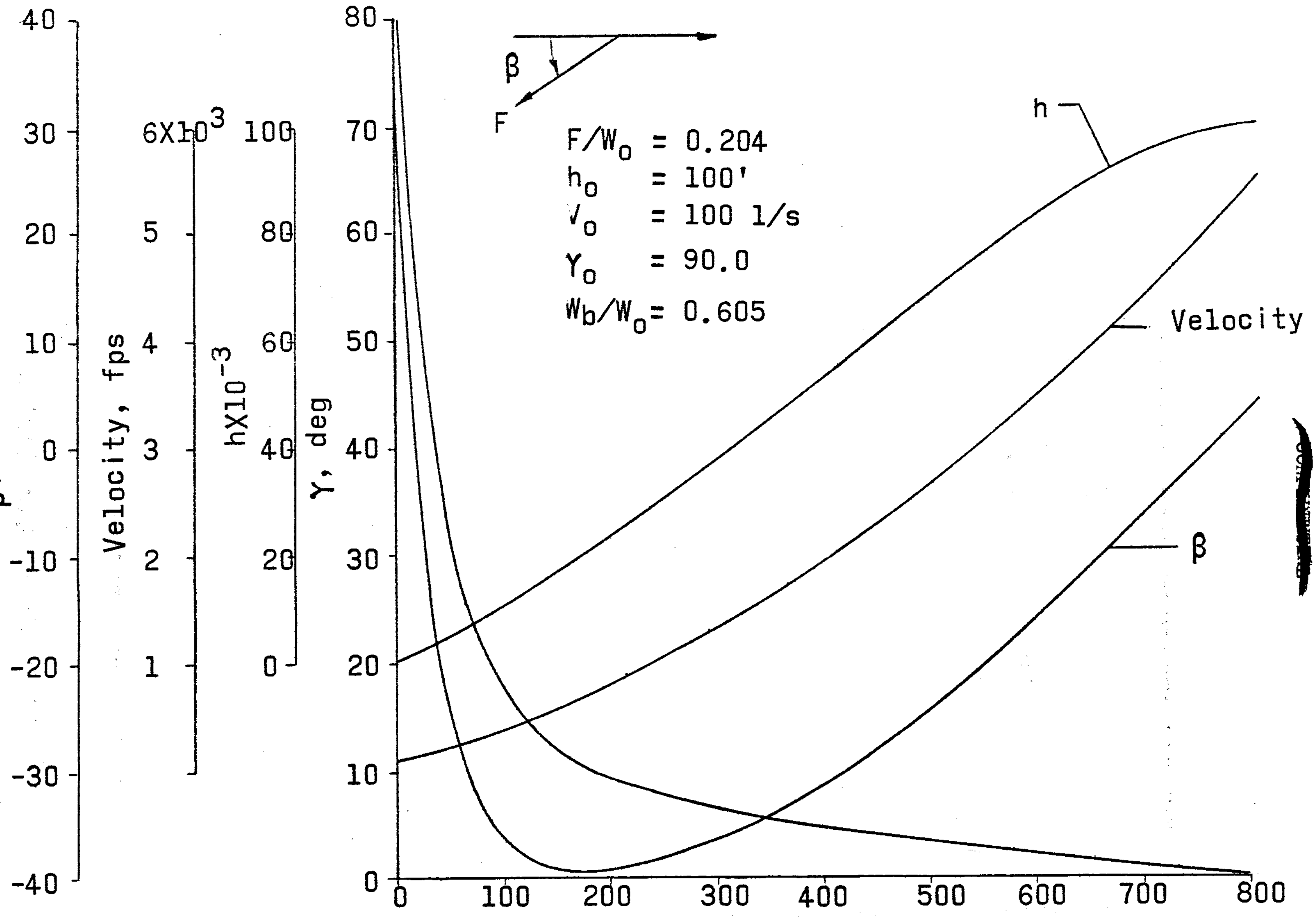

Figure 20.- Time history for a lunar take-off to a 100,000 ft. parking orbit.

[redacted]

[redacted]

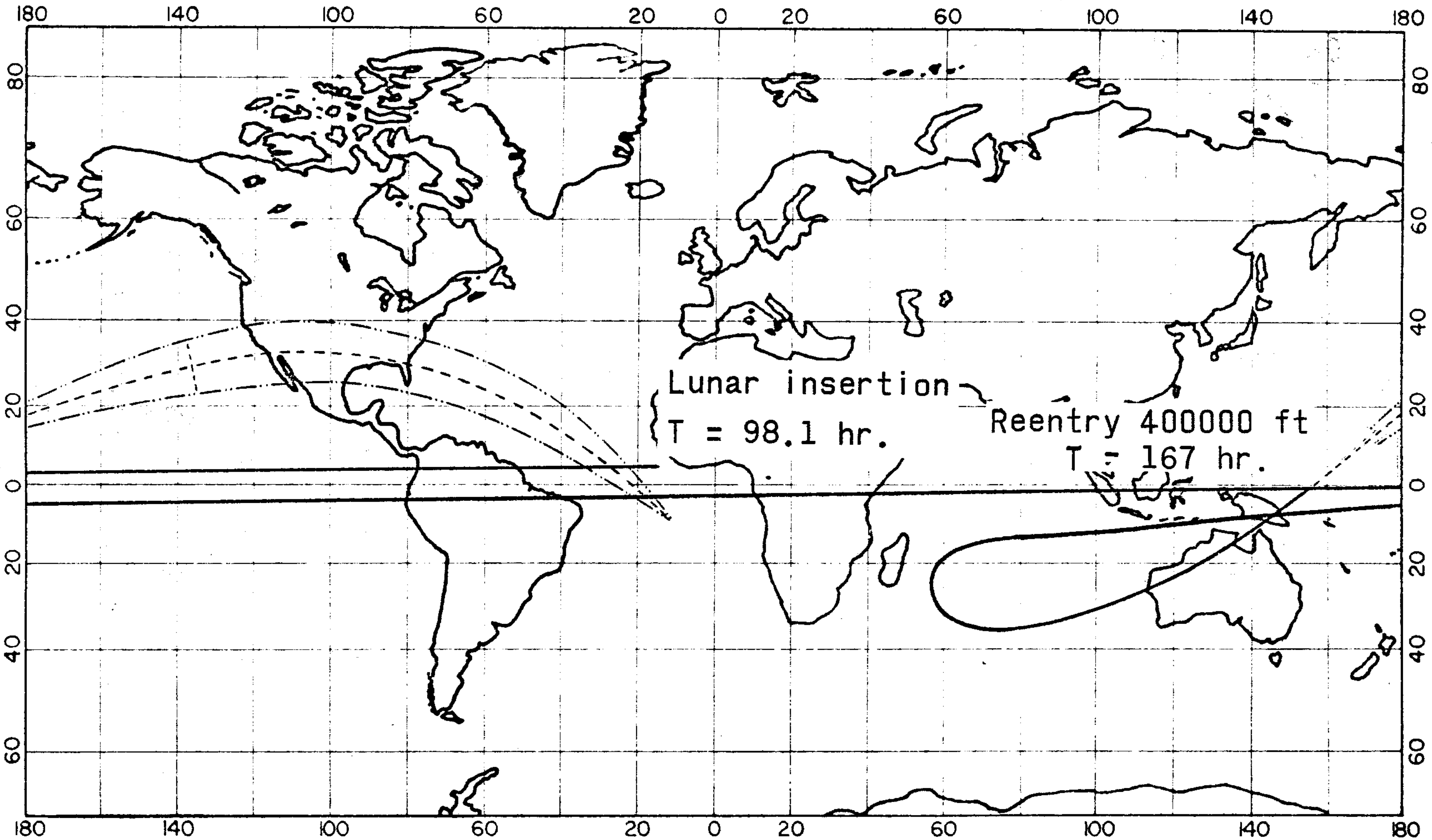

Figure 21.- Earth track of transearth and reentry phases.

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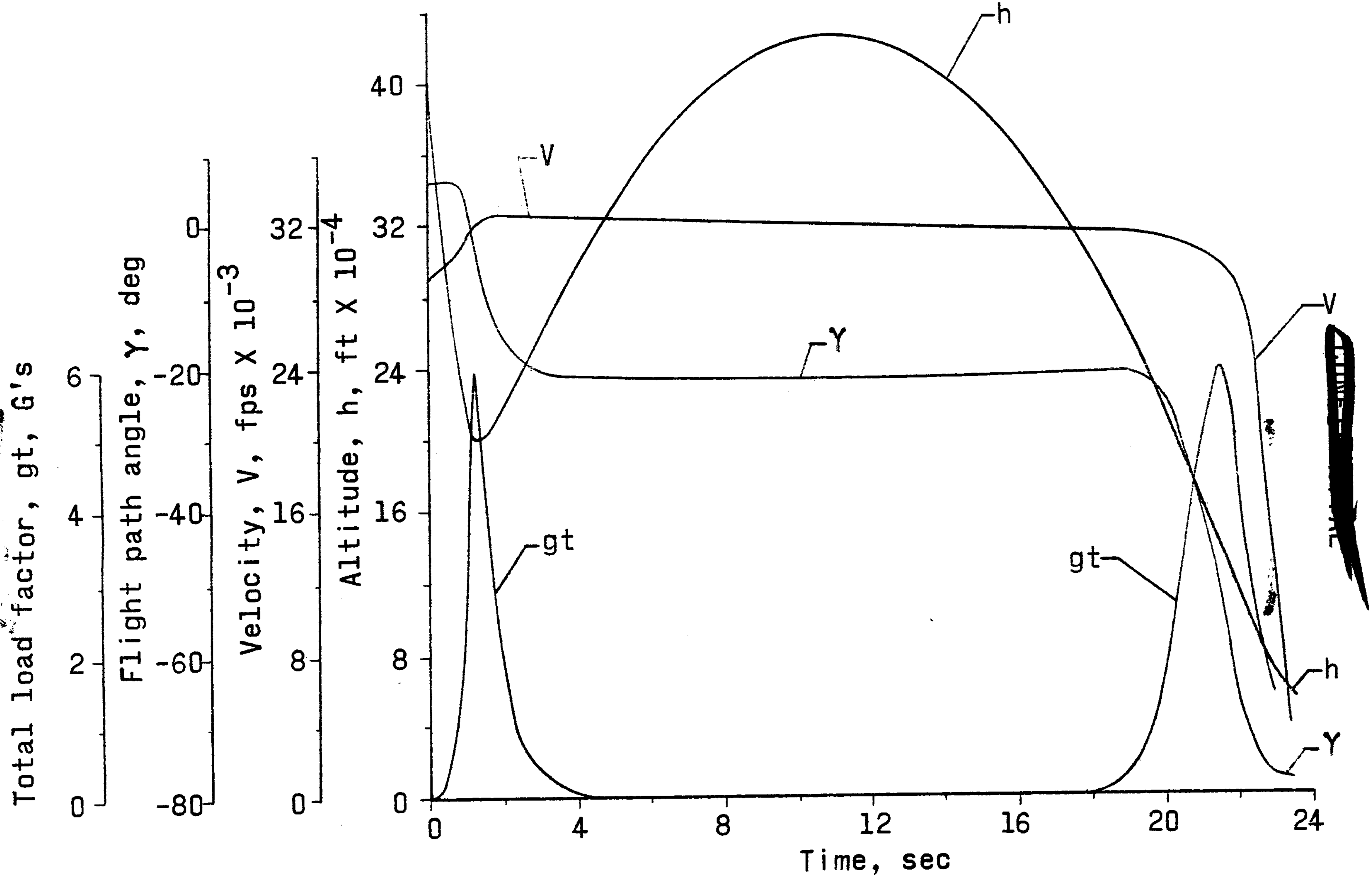

Figure 22.- Time history from reentry to near-landing.

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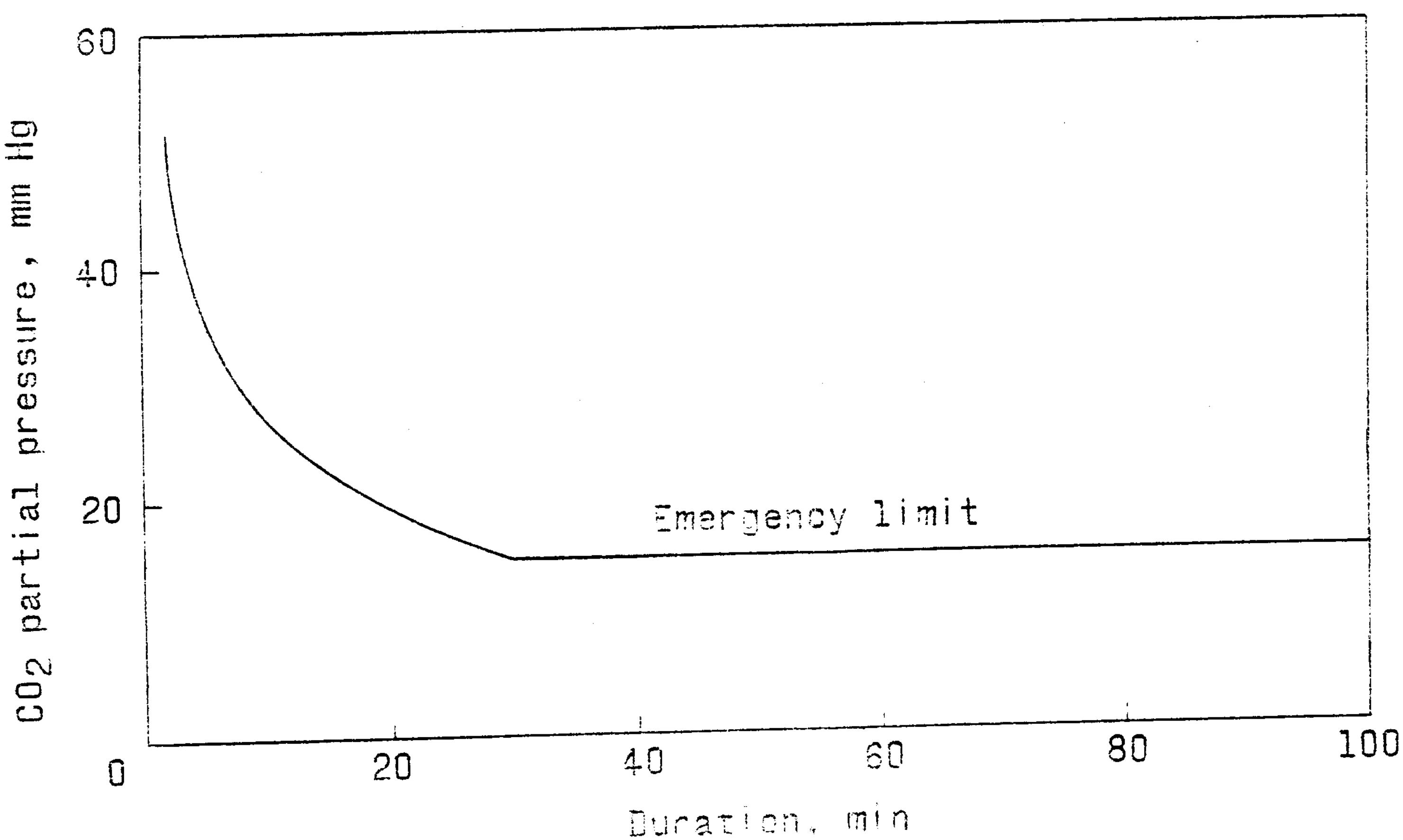

Figure 23.- Emergency carbon dioxide limit.

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[redacted]

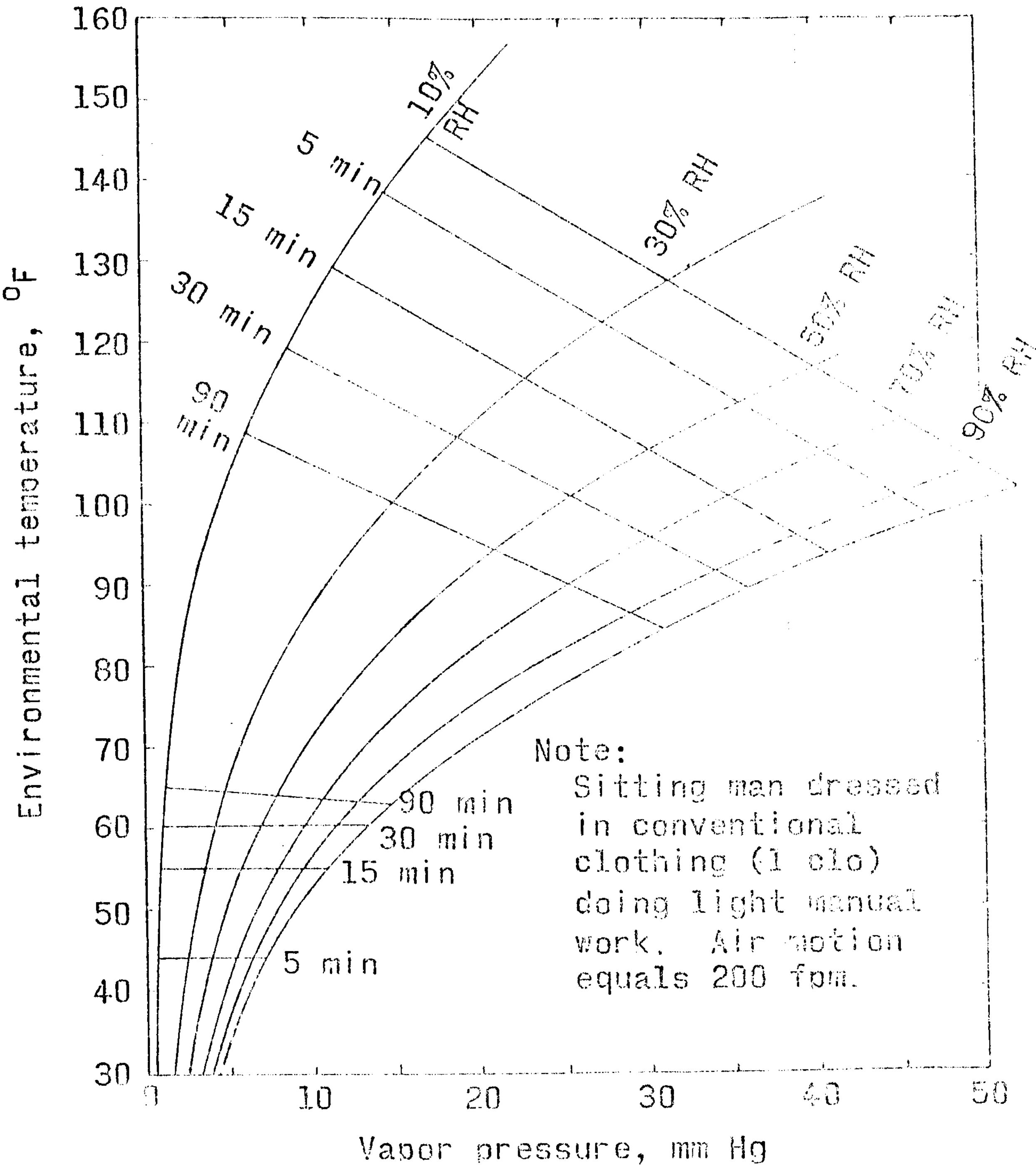

Figure 24.- Temperature and humidity nominal limit.

[redacted]

[redacted]

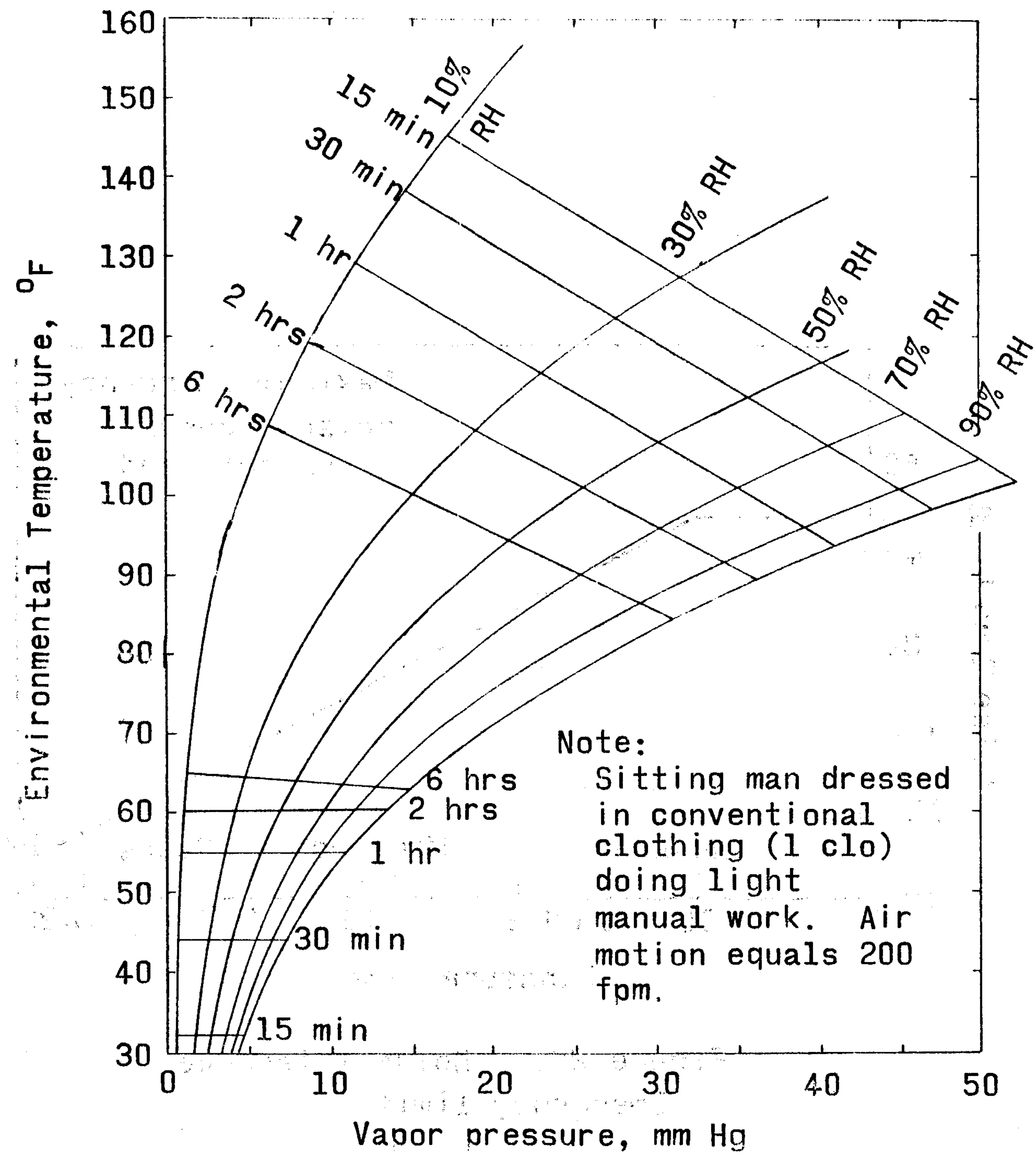

Figure 25.- Temperature and humidity emergency limit.

[redacted]

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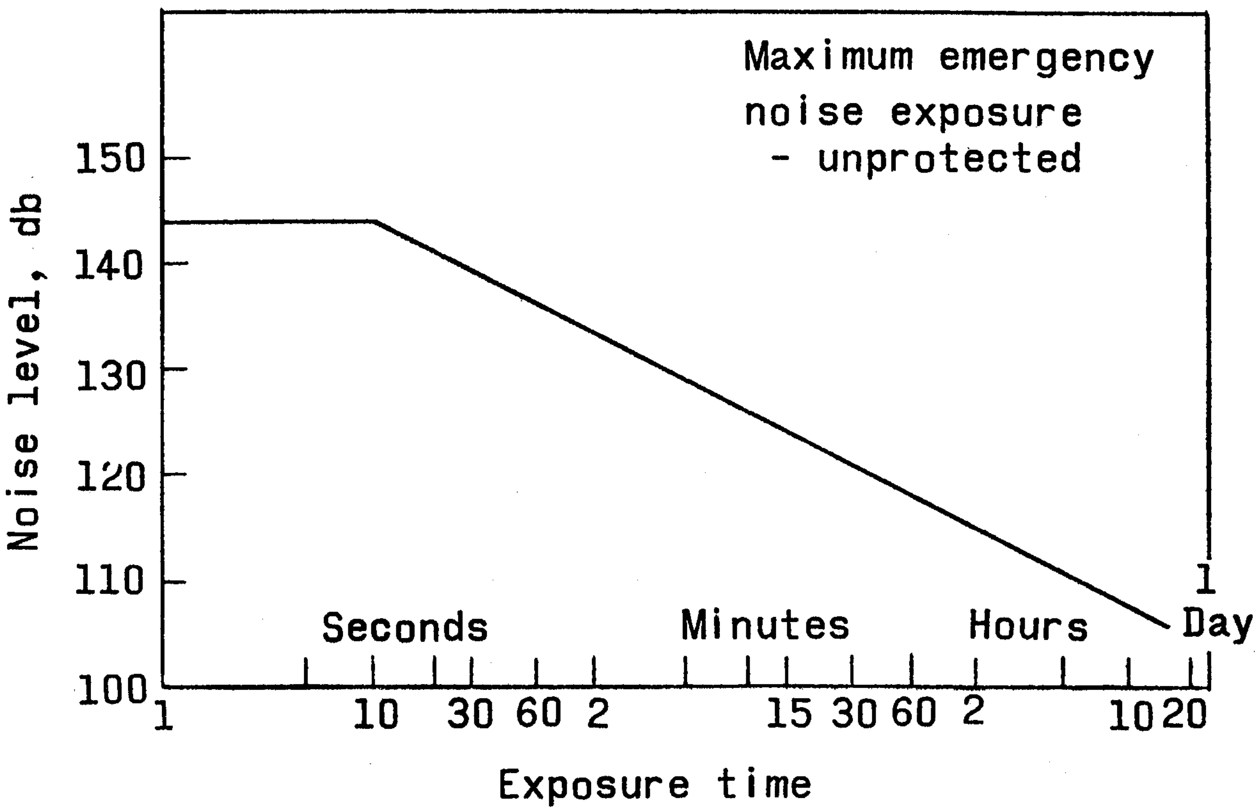

Figure 26.- Noise tolerance.
Emergency limit.

[redacted]

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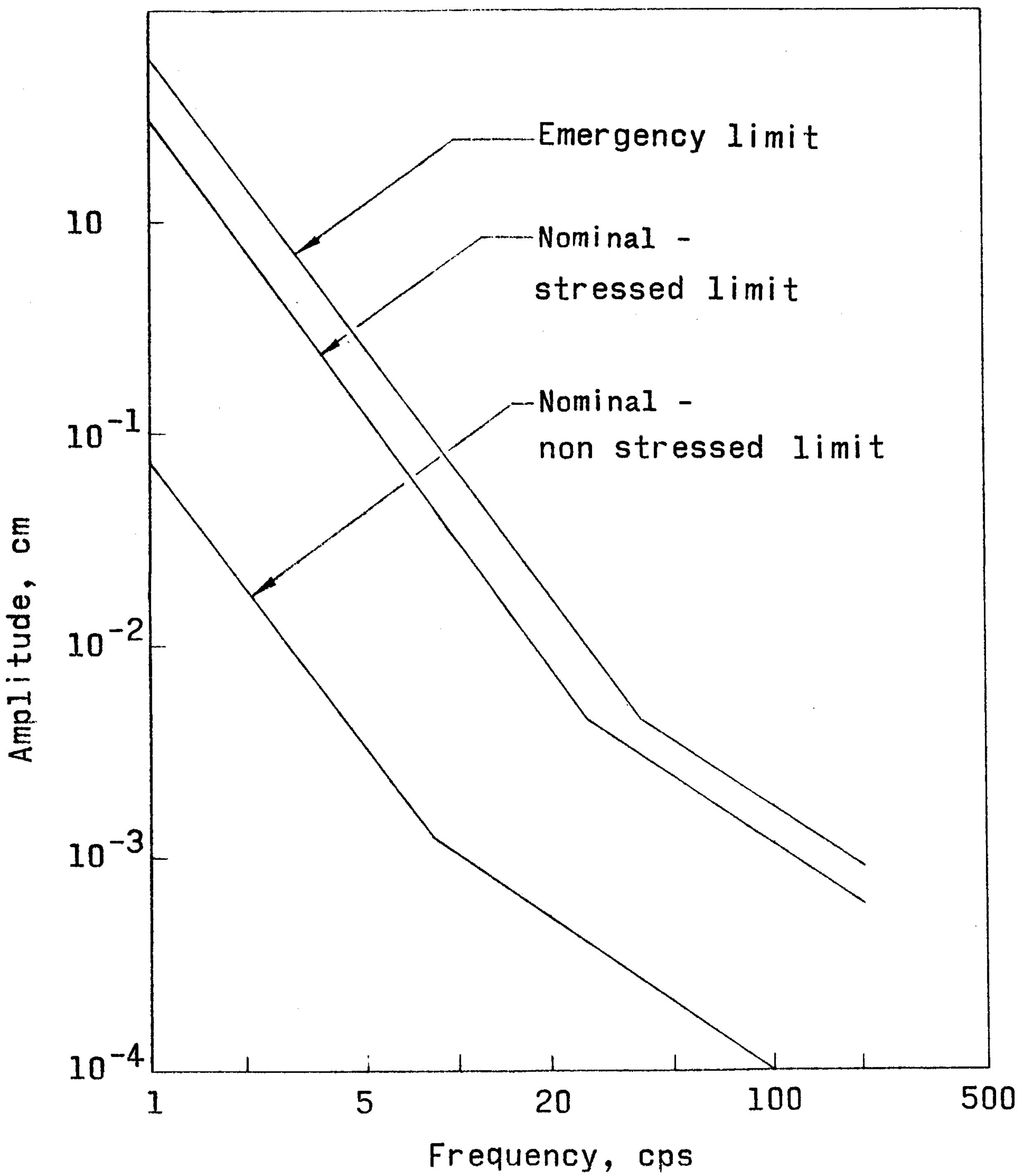

Figure 27.- Vibration limits.

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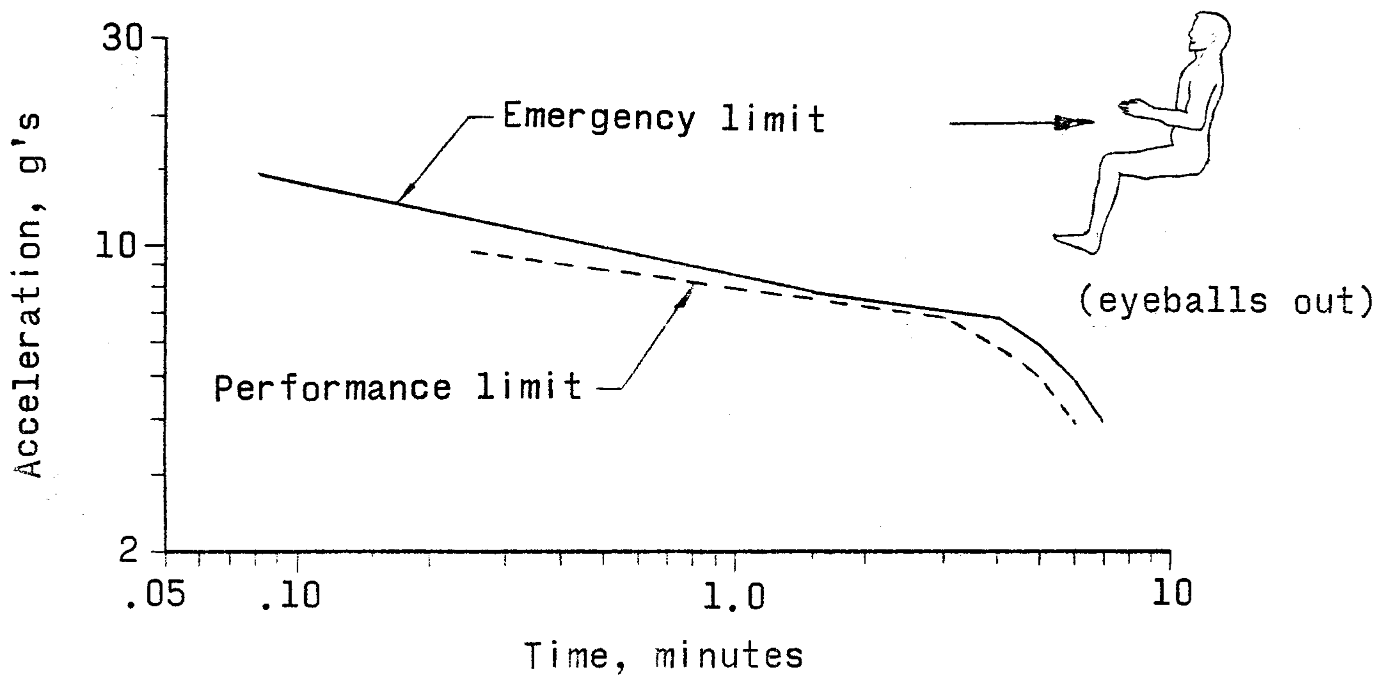

Figure 28.- Sustained acceleration. (References C-1 thru C-4 and C-7)

[redacted]

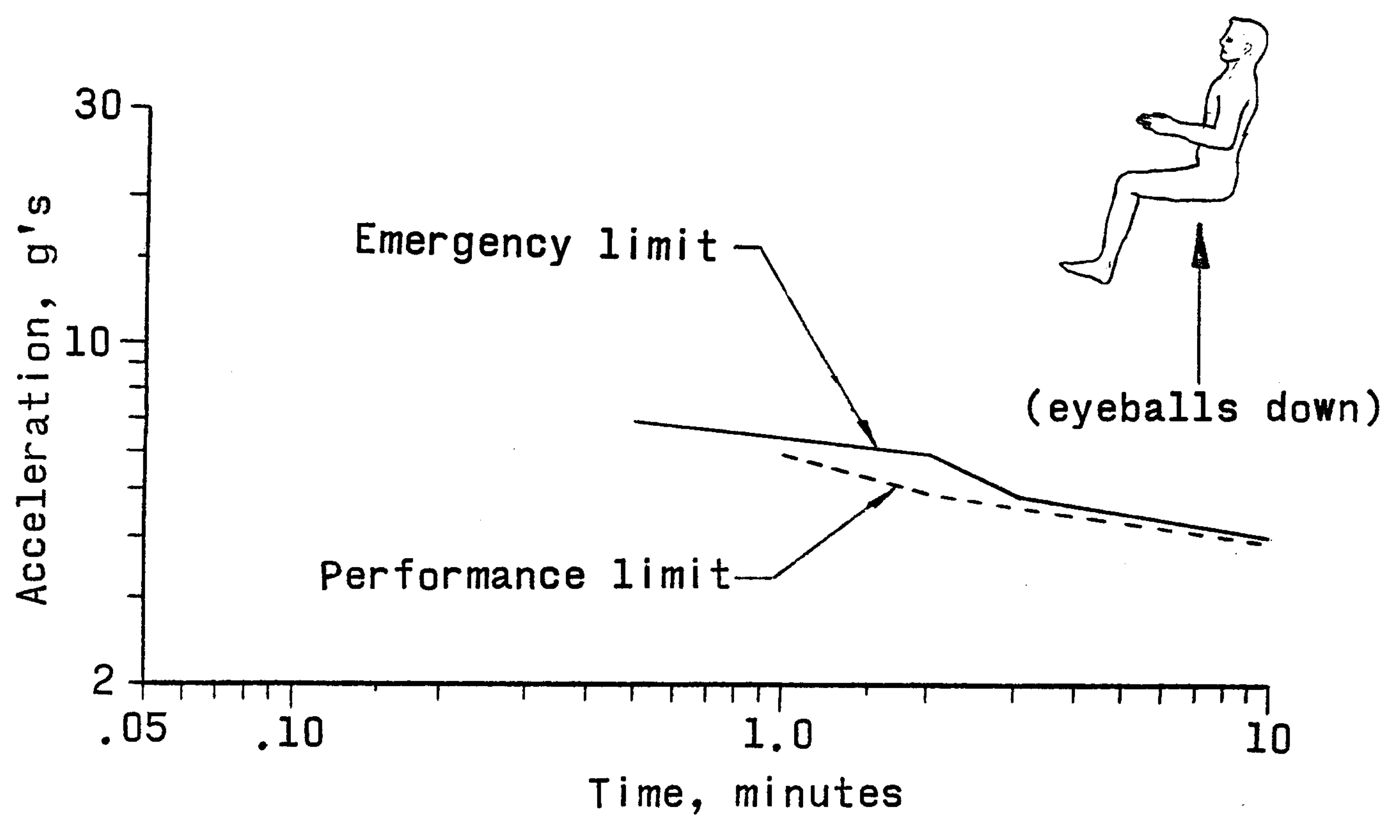

Figure 29.- Sustained acceleration. (References C-1, C-5, and C-6)

[redacted]

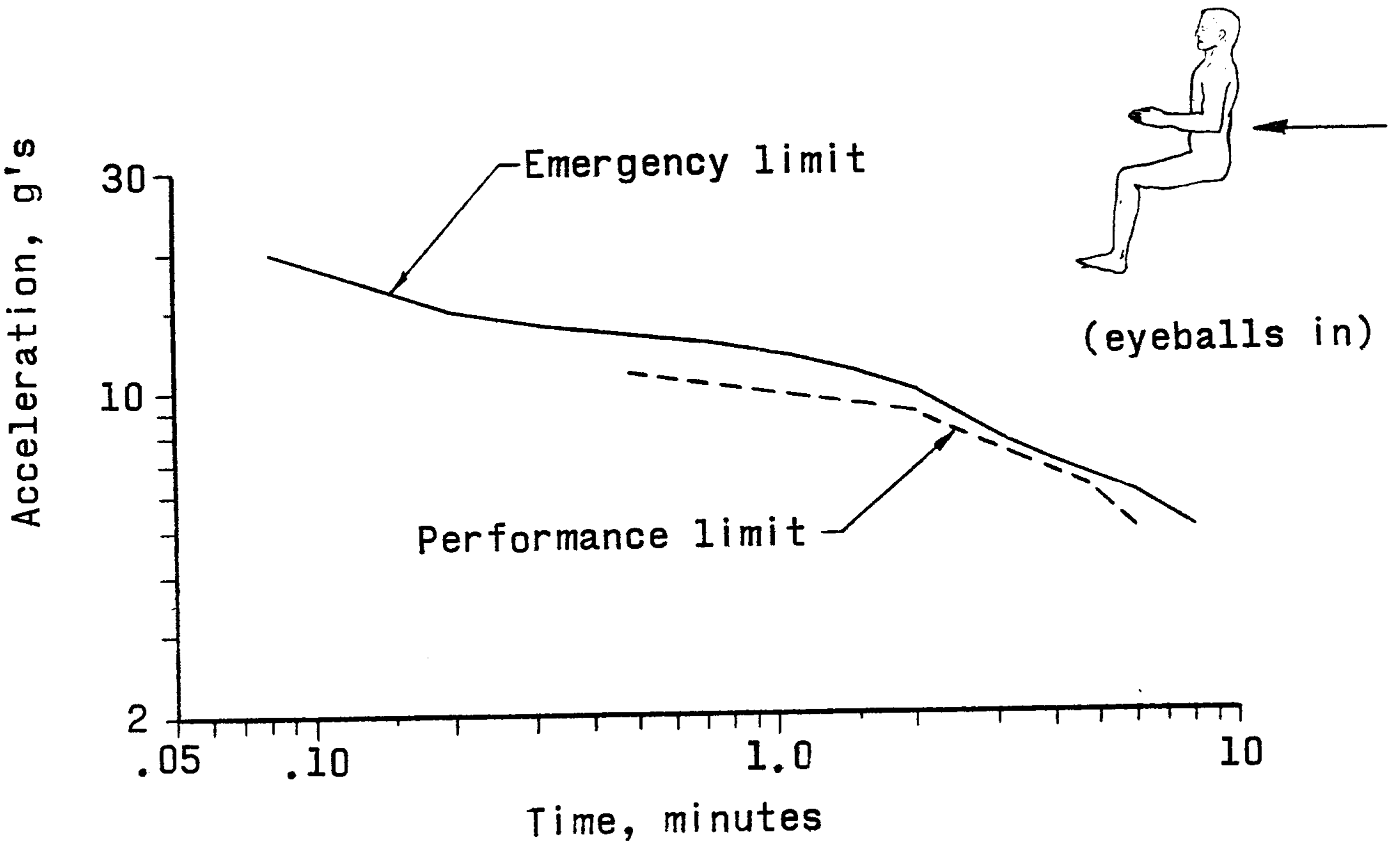

Figure 30.- Sustained acceleration. (References C-1 thru C-4 and C-8)

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[redacted]

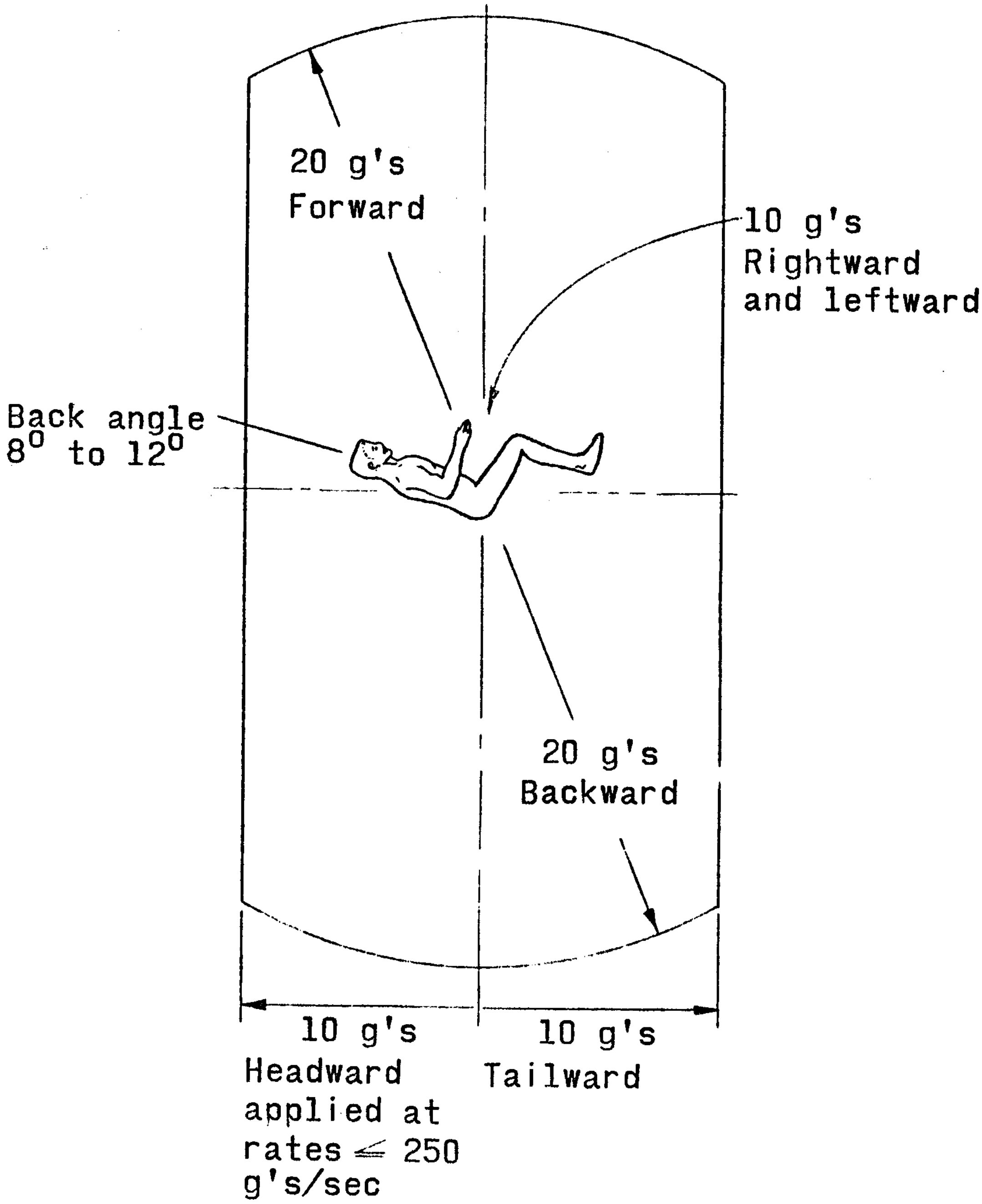

Figure 31.- Impact accelerations - nominal limits.

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[redacted]

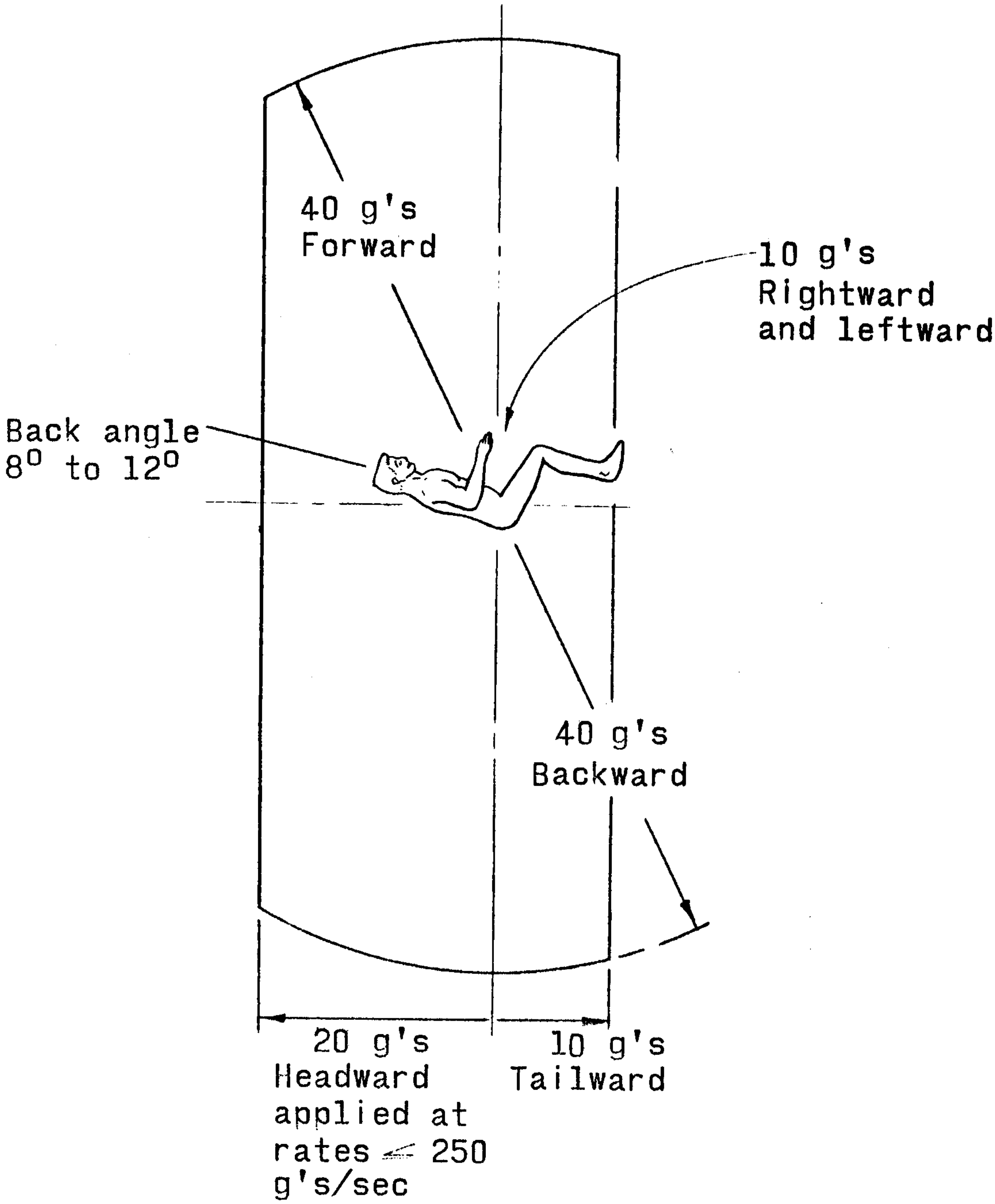

Figure 32.- Impact accelerations - emergency limits

[redacted]

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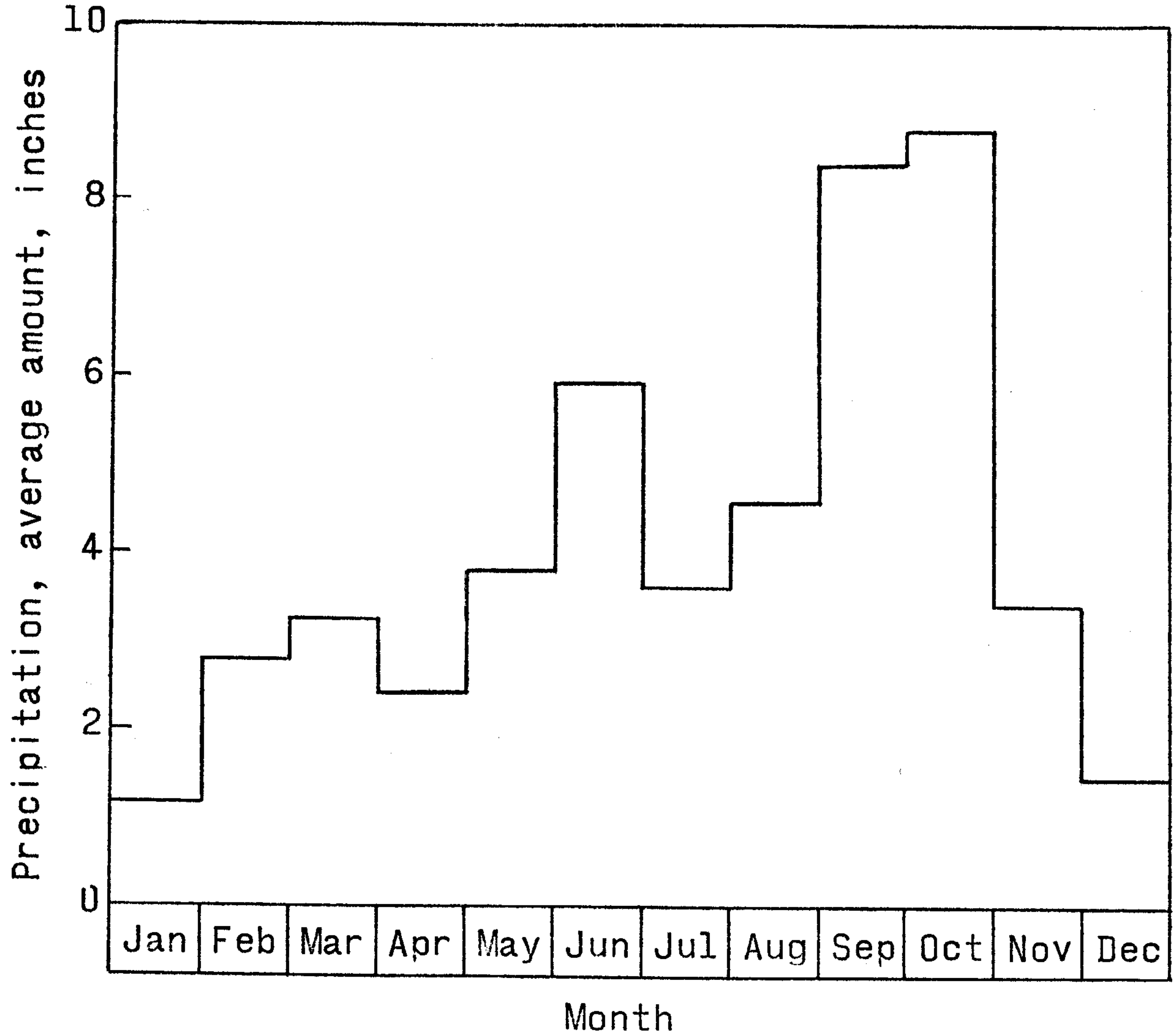

Figure 33.- Average monthly precipitation Patrick Airforce Base, Florida.

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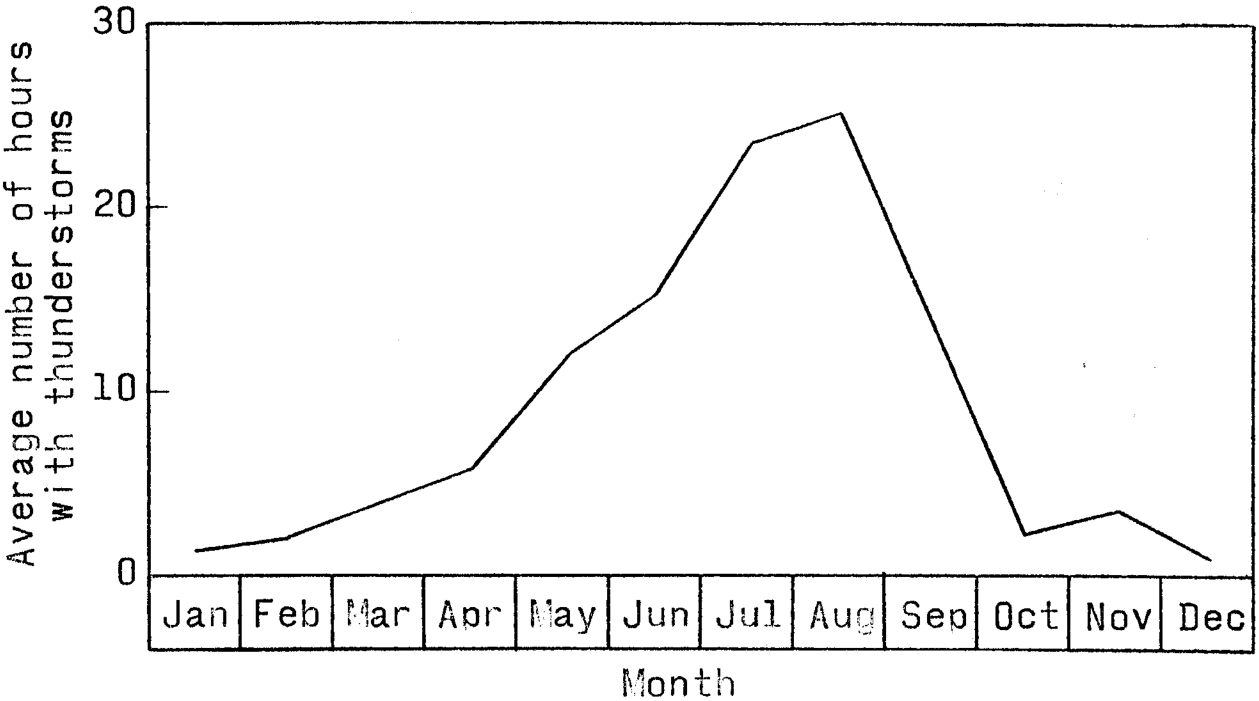

Figure 34.- Average number of hours with thunderstorms Patrick Airforce Base, Florida.

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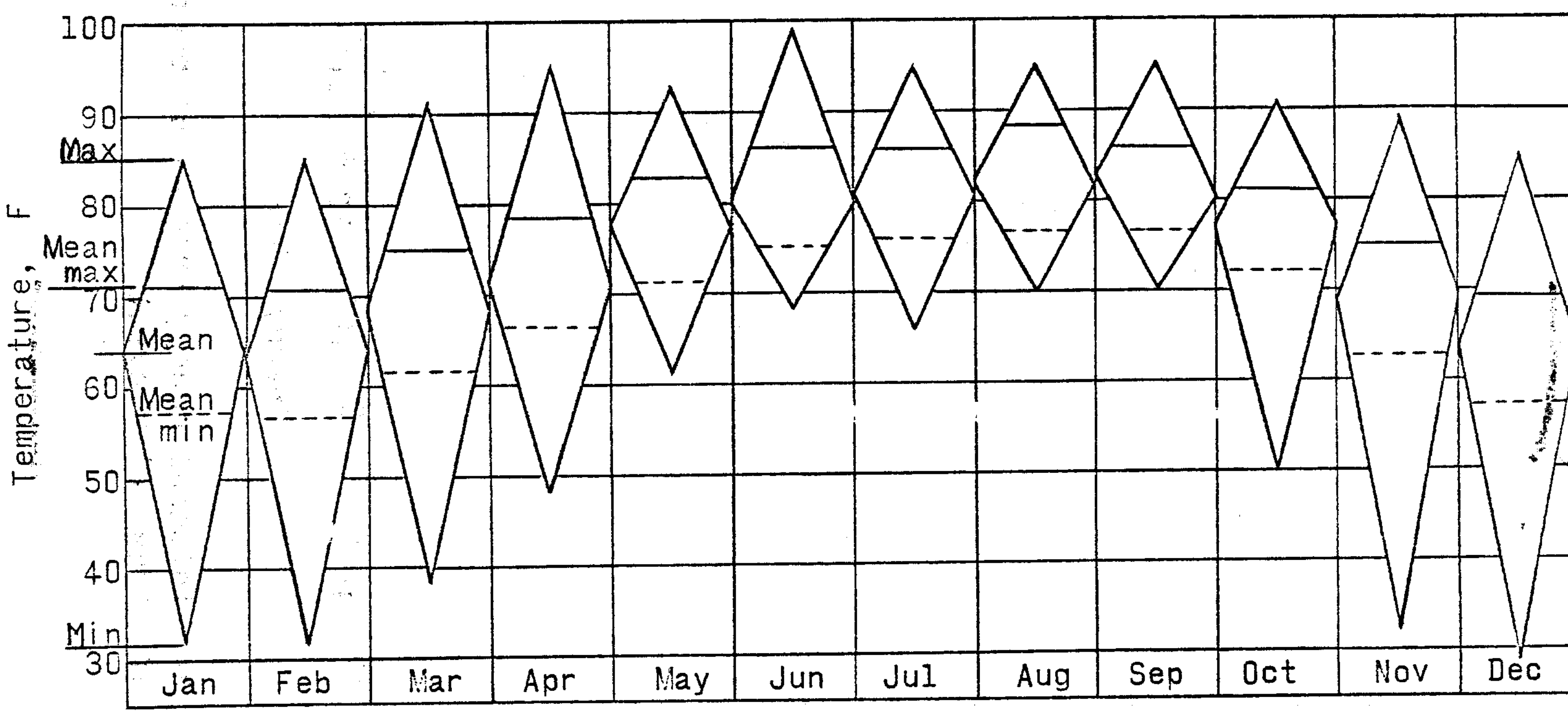

Figure 35.- Monthly temperature variations at Patrick Air Force Base, Florida.

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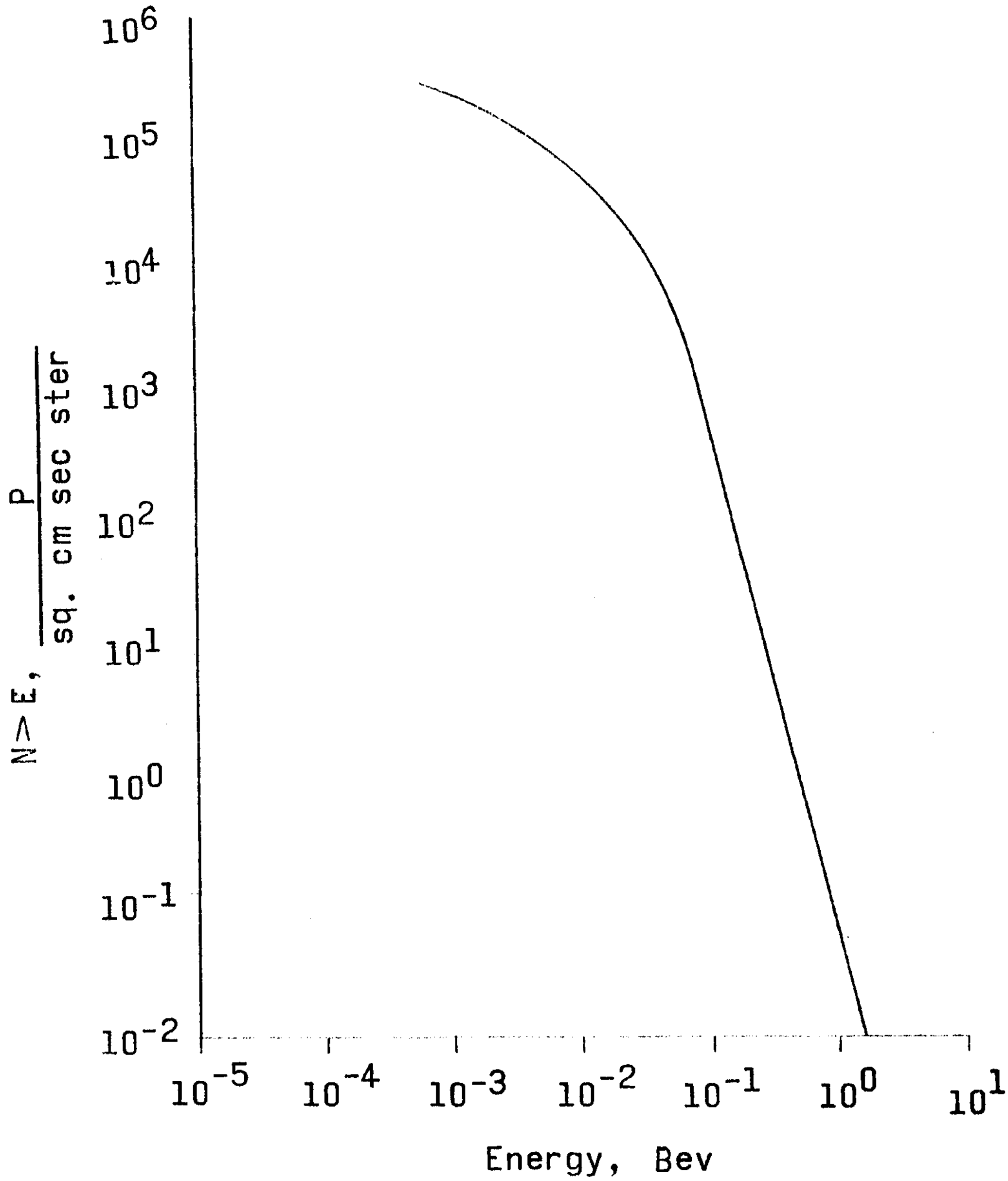

Figure 36.- Integral energy spectra of protons for May 10, 1959 solar event.

[redacted]

[redacted]

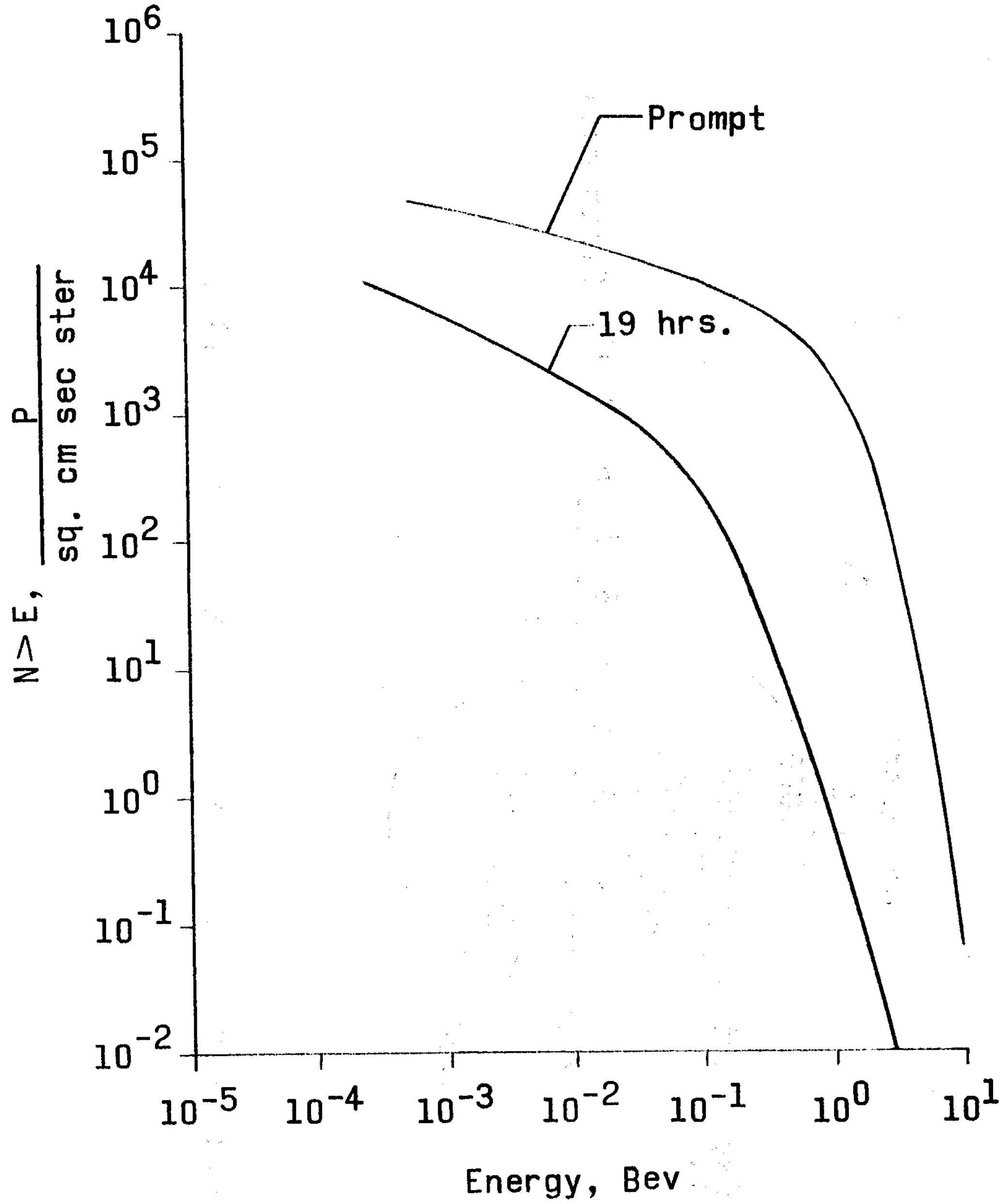

Figure 37.- Integral energy spectrum of protons for the February 23, 1956 solar event.

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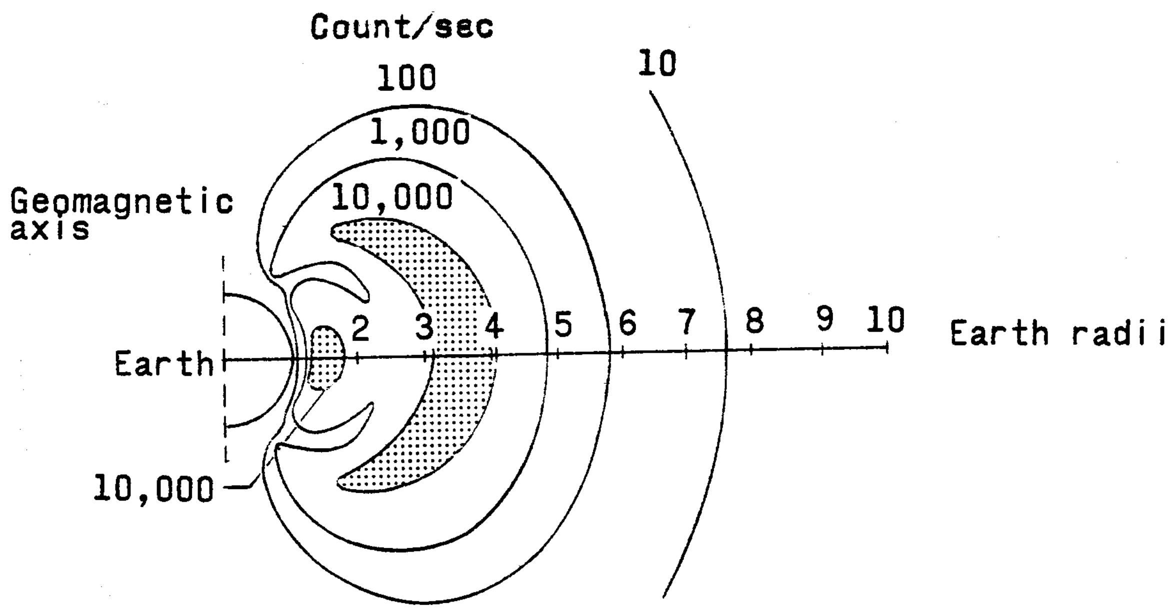

Figure 38.- Model of Van Allen radiation belts.

[redacted]

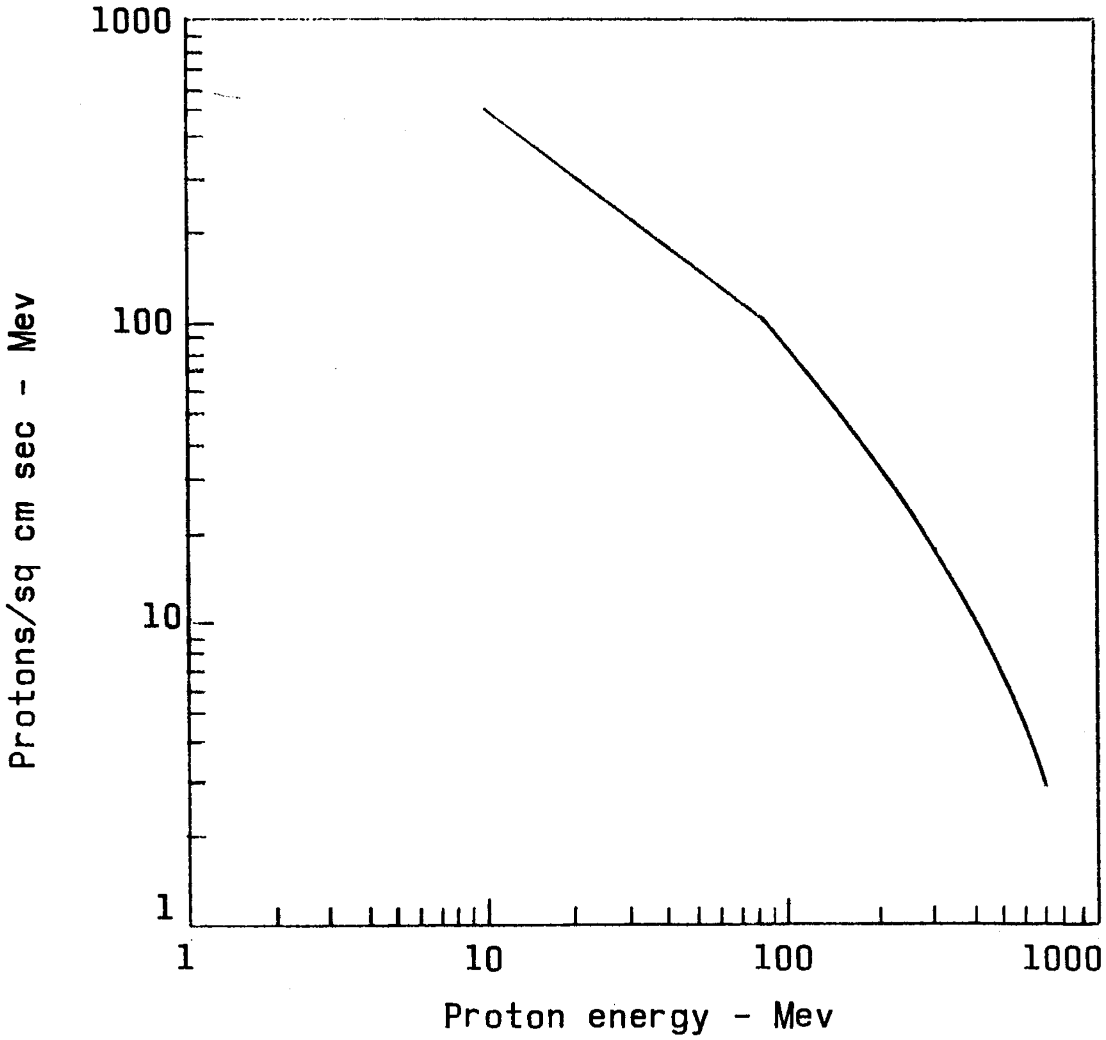

Figure 39.- Differential proton spectrum for the inner Van Allen belt at the geomagnetic equator.

[redacted]

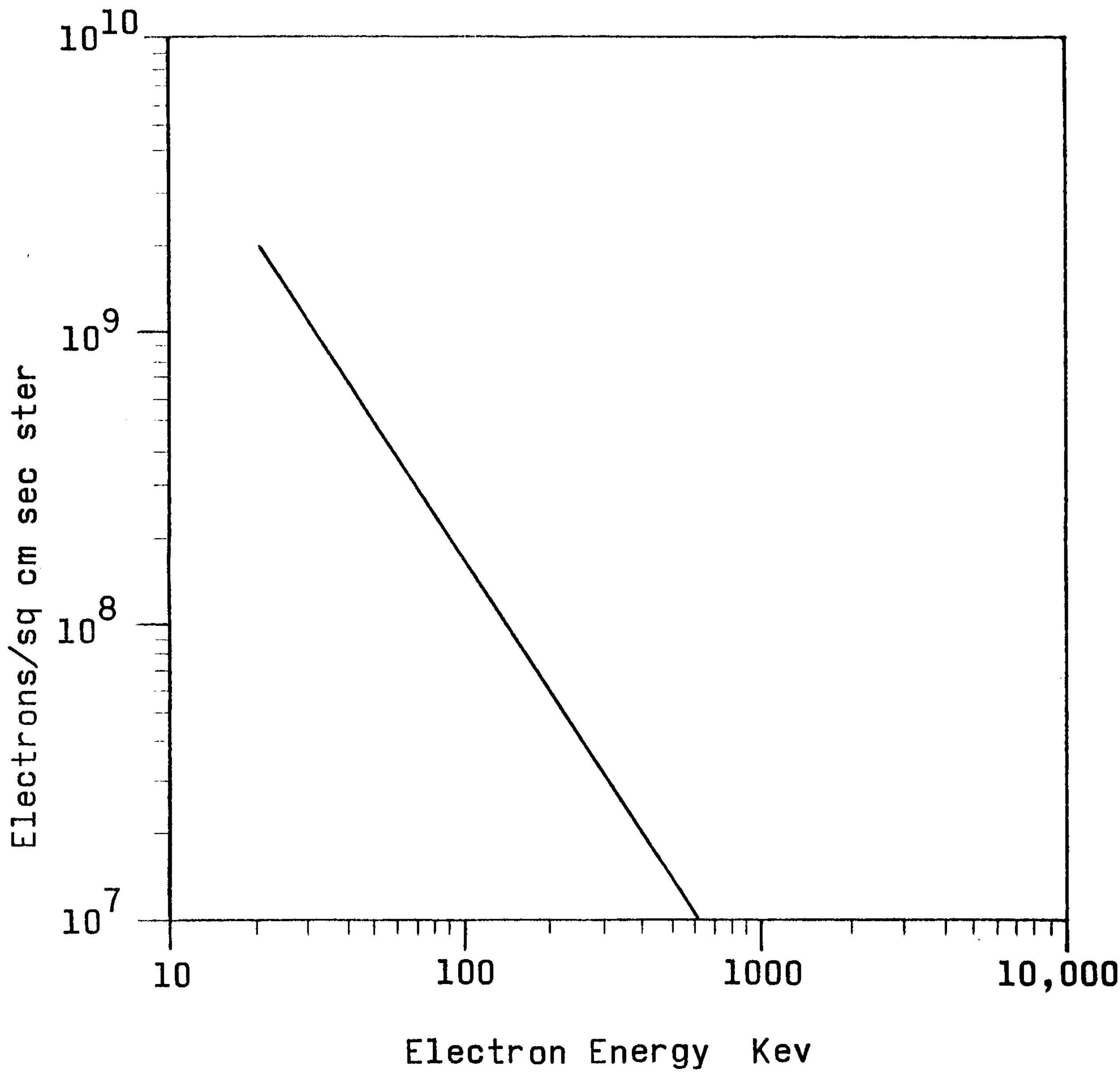

Figure 40.- Differential electron spectrum for the inner belt.

[redacted]

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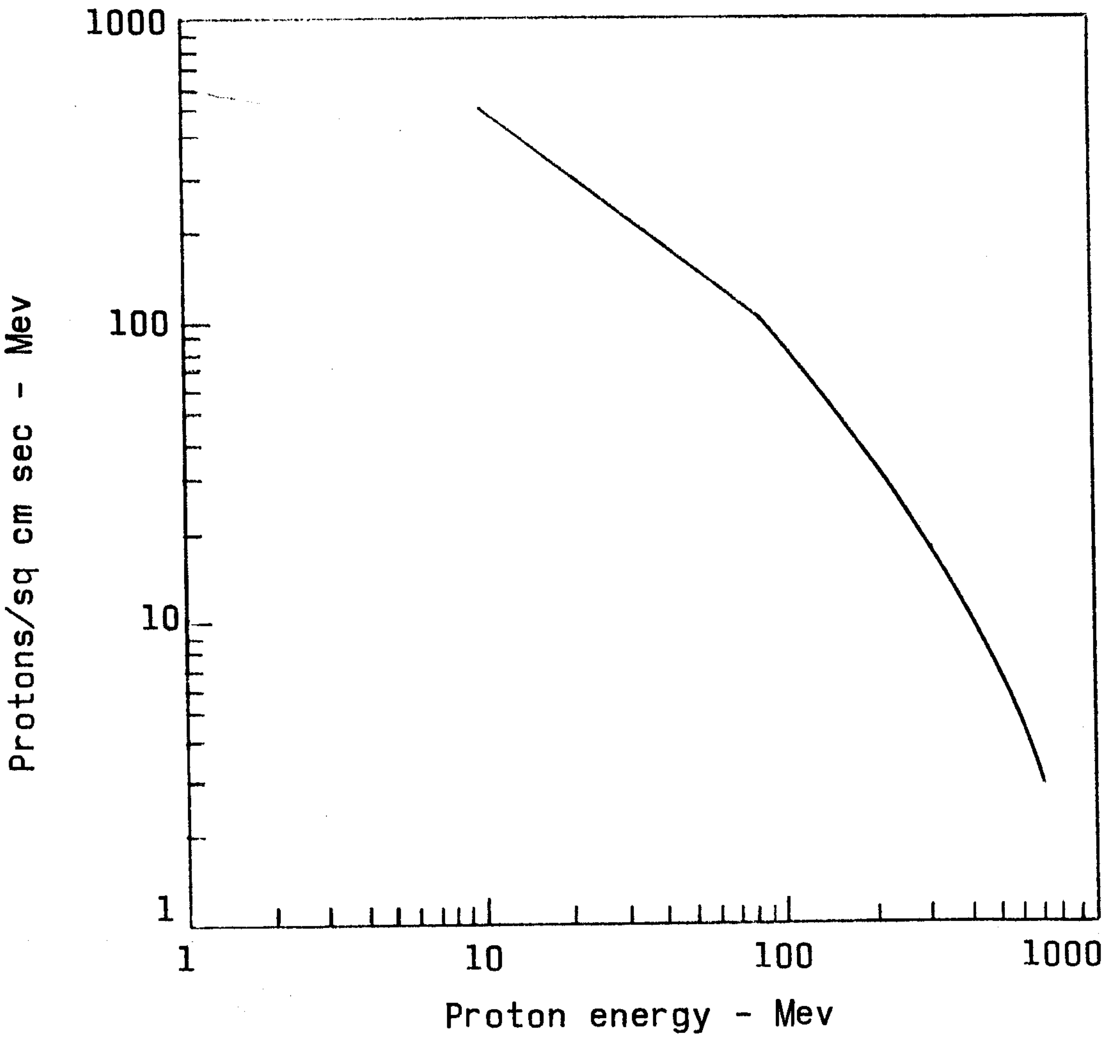

Figure 39.- Differential proton spectrum for the inner Van Allen belt at the geomagnetic equator.

[redacted]

[redacted]

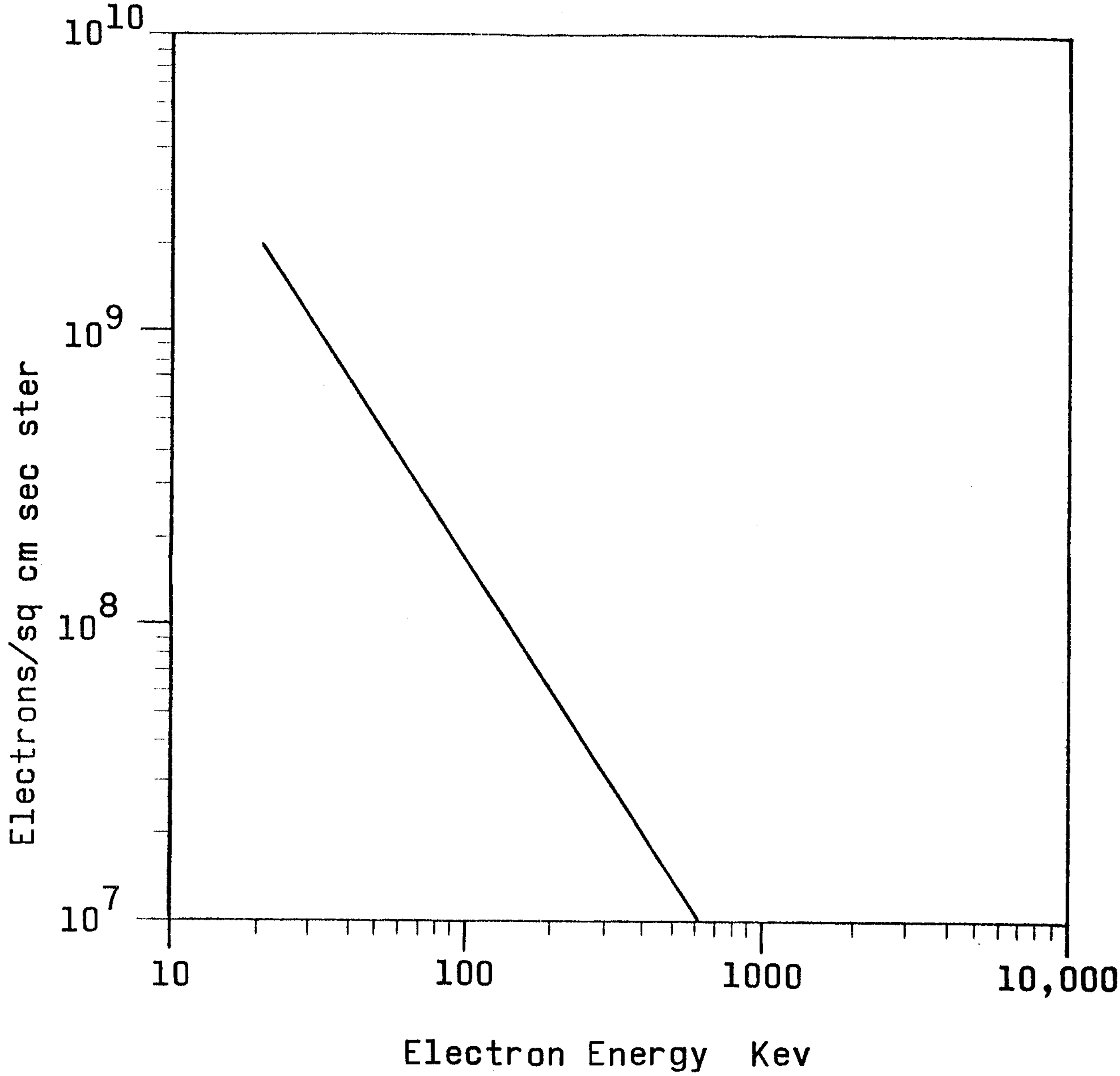

Figure 40.- Differential electron spectrum for the inner belt.

[redacted]

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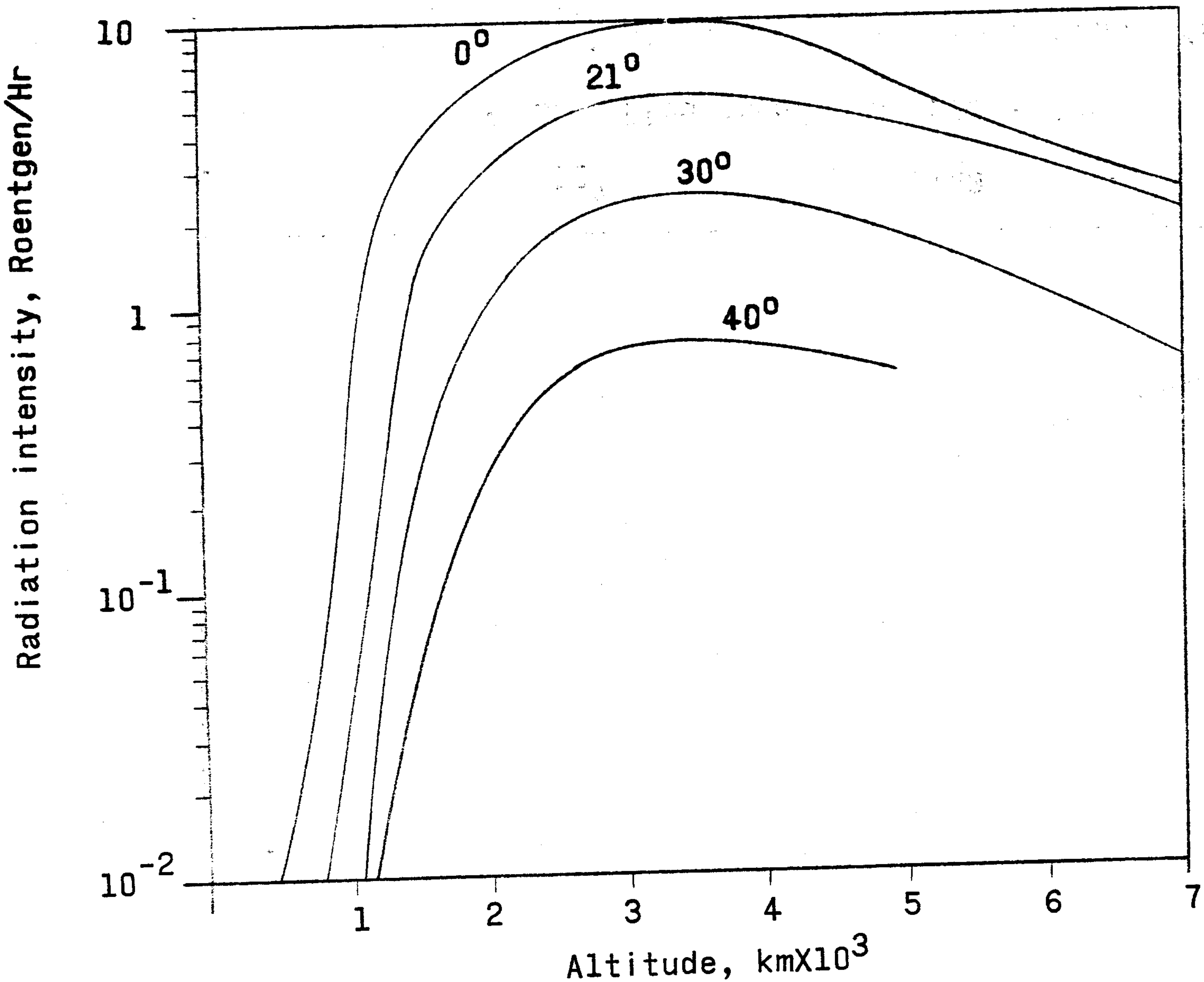

Figure 41.- Radiation intensity distribution for the inner belt.

[redacted]

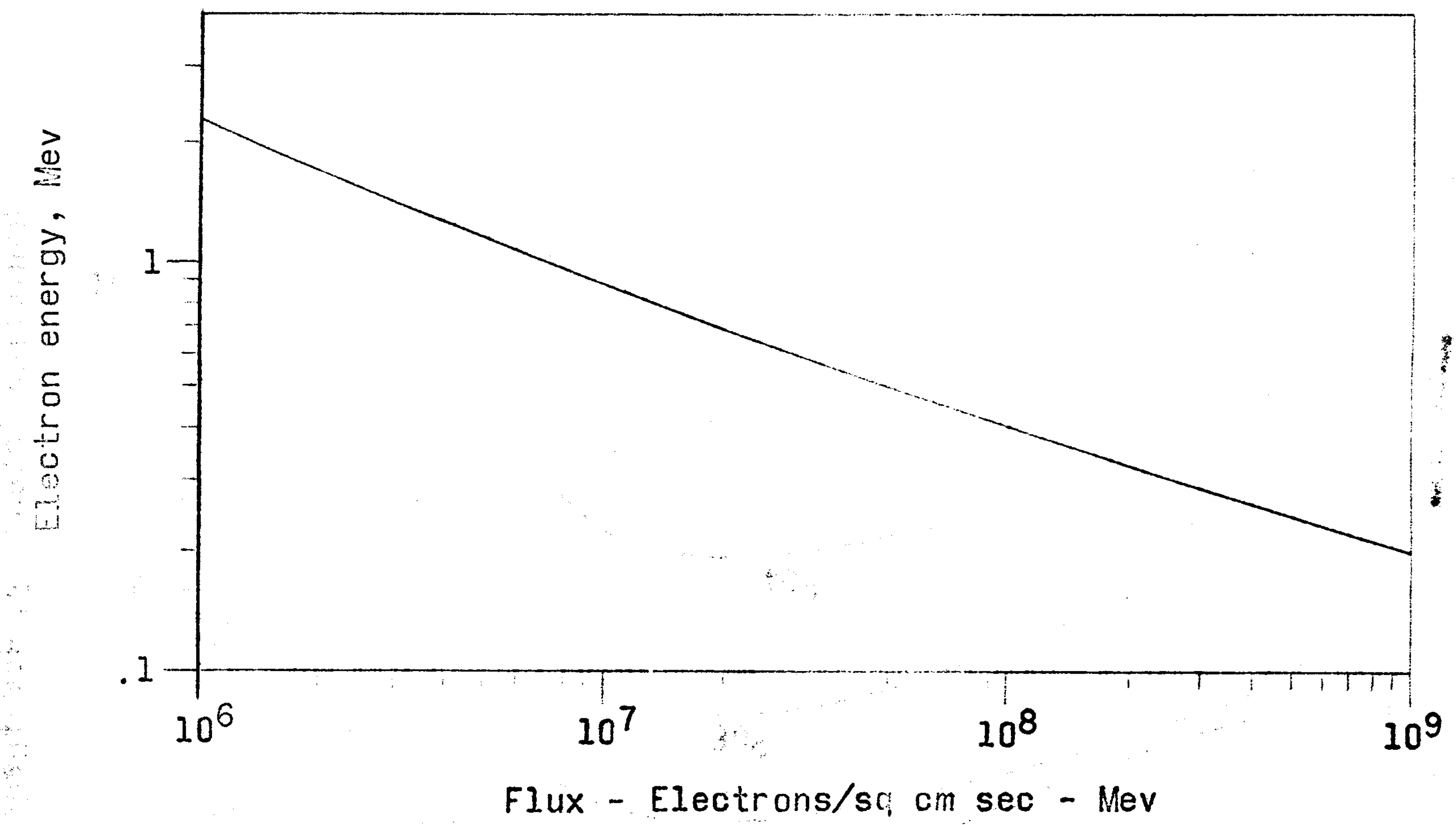

Figure 42.- Differential electron spectrum for the outer belt.

[redacted]

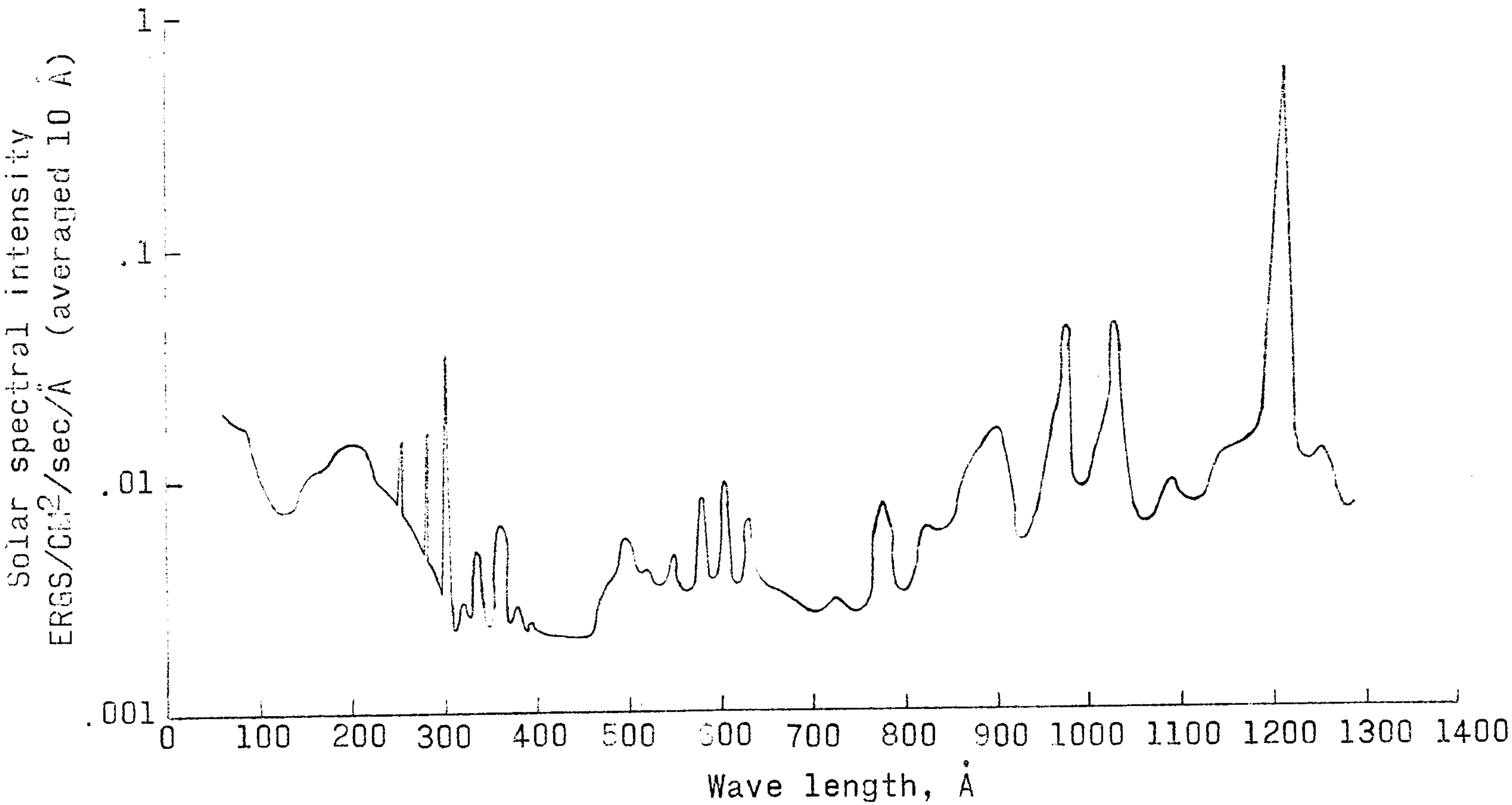

Figure 43.- Electromagnetic spectrum for solar radiation.

[redacted]

[redacted]

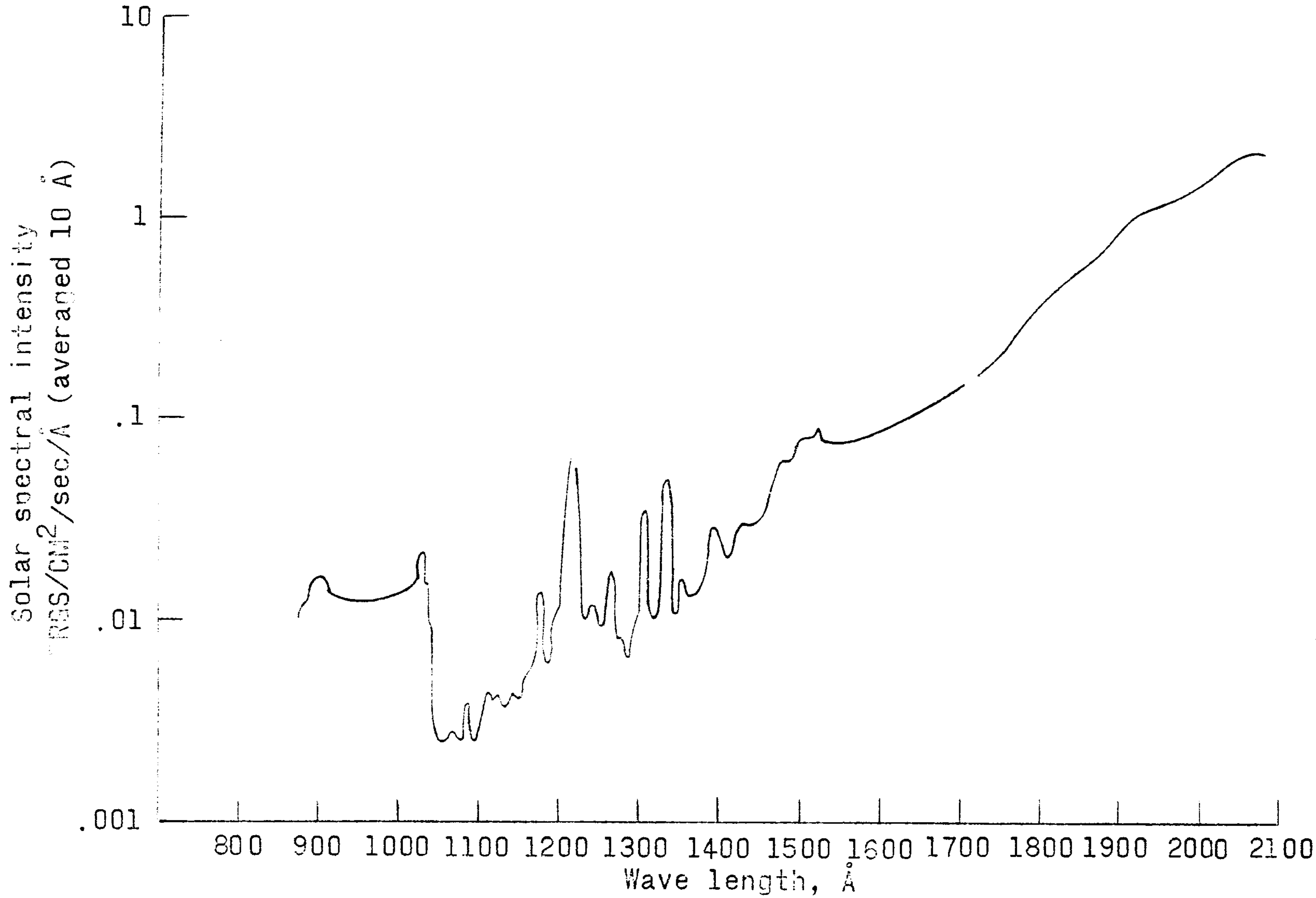

Figure 44.- Electromagnetic spectrum for solar radiation.

[redacted]

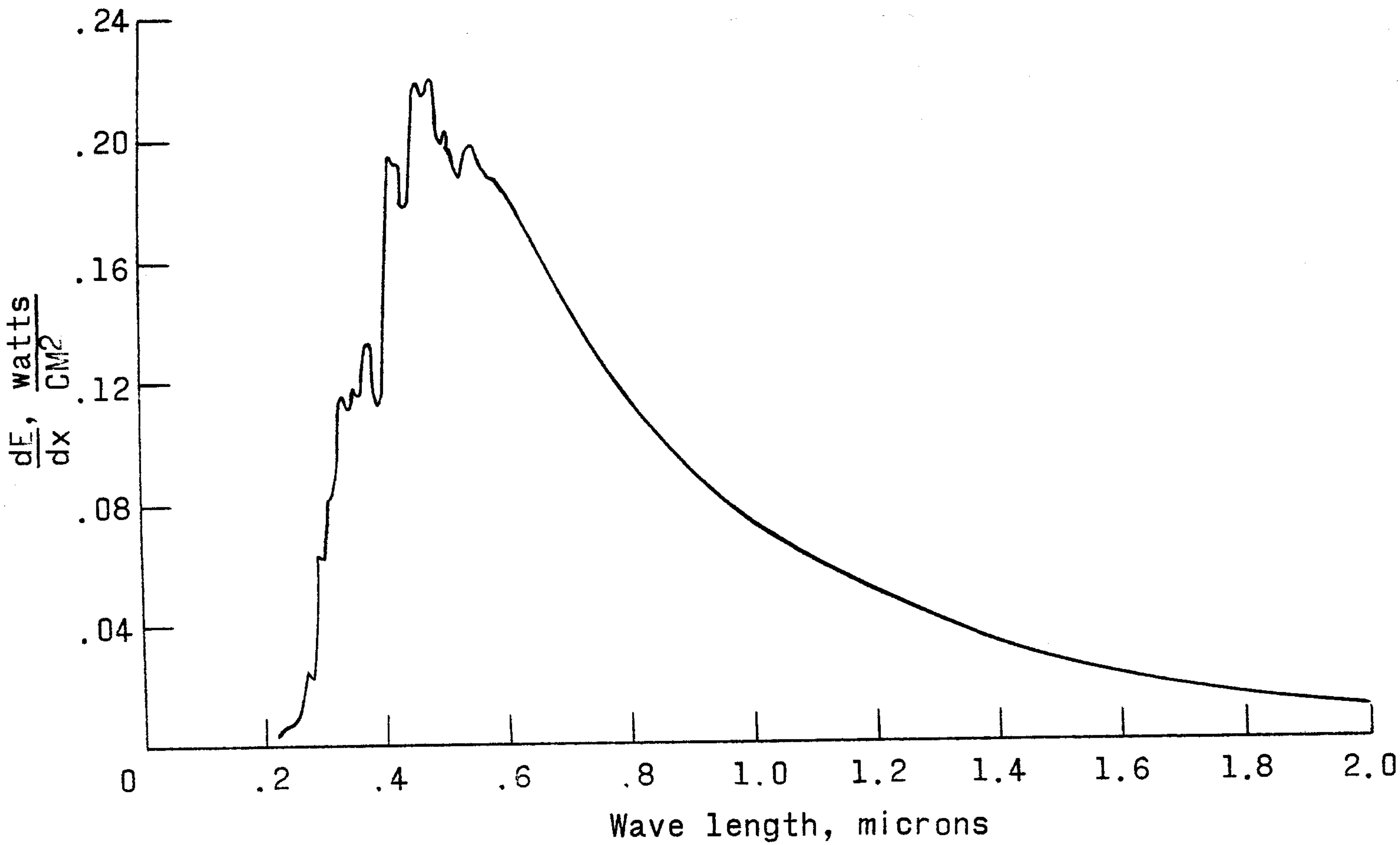

Figure 45.- Electromagnetic spectrum for solar radiation.

[redacted]

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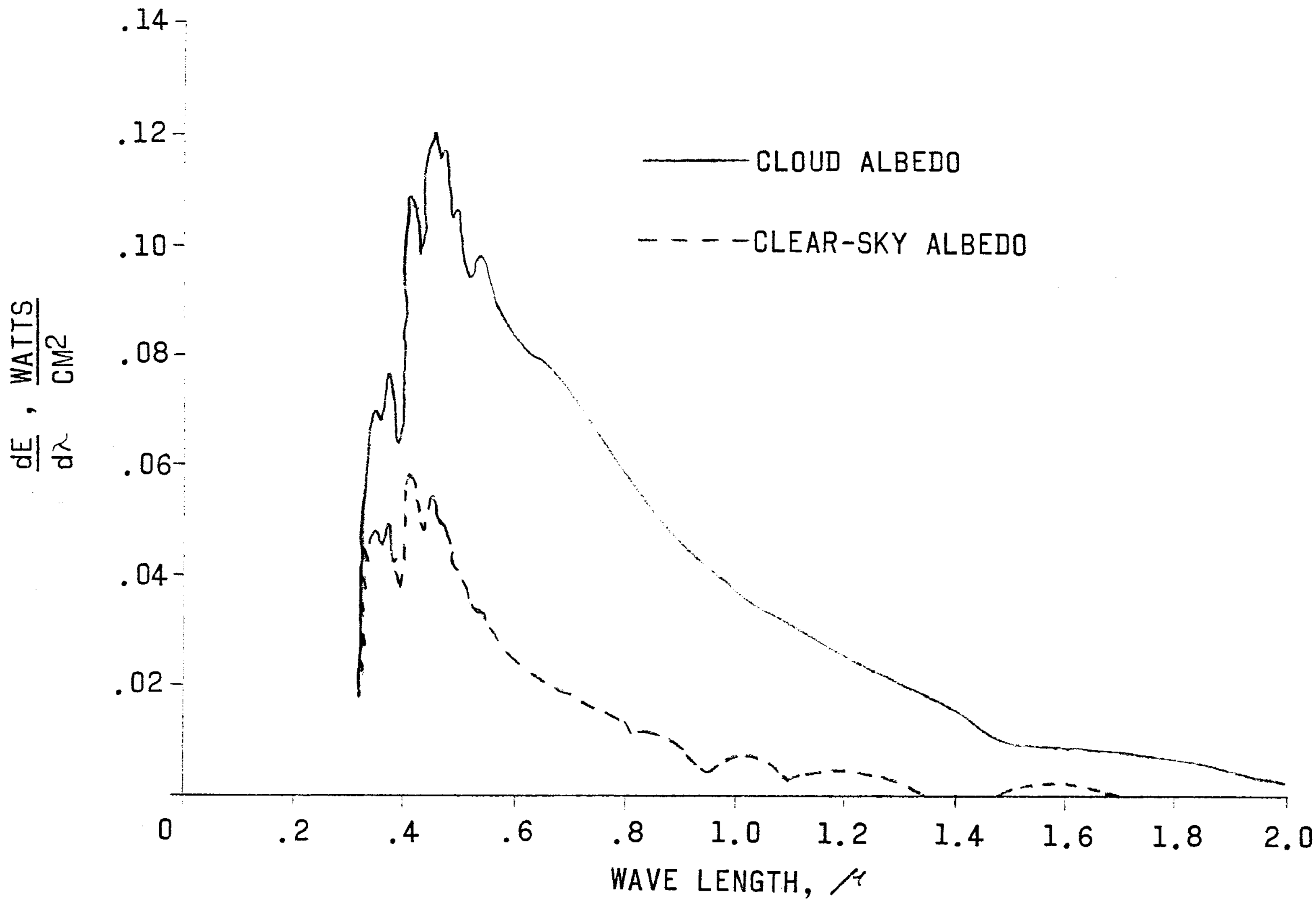


Figure 46.- Spectrum of the Earth's albedo.

[redacted]

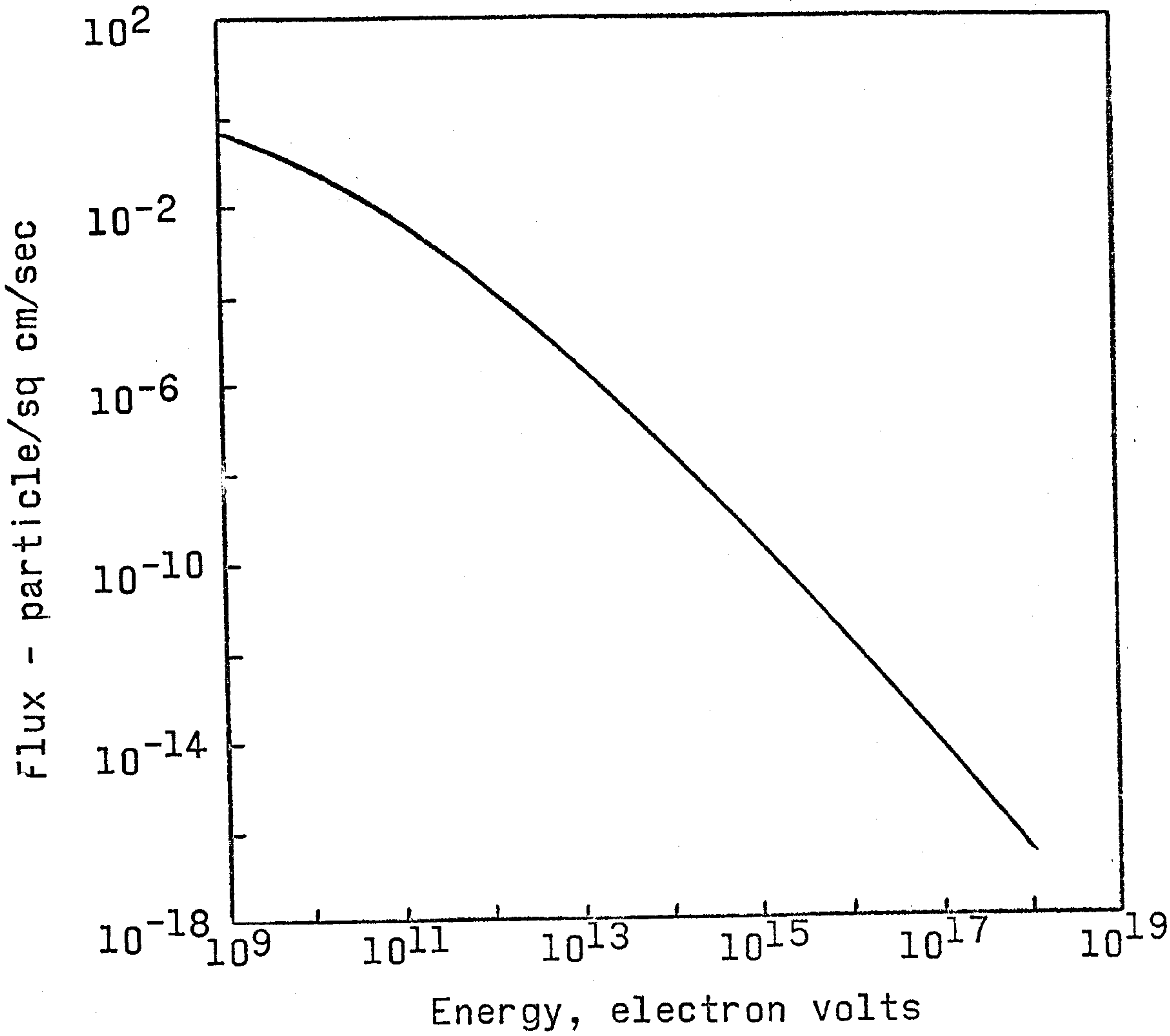


Figure 47.- Galactic cosmic ray flux.

[redacted]

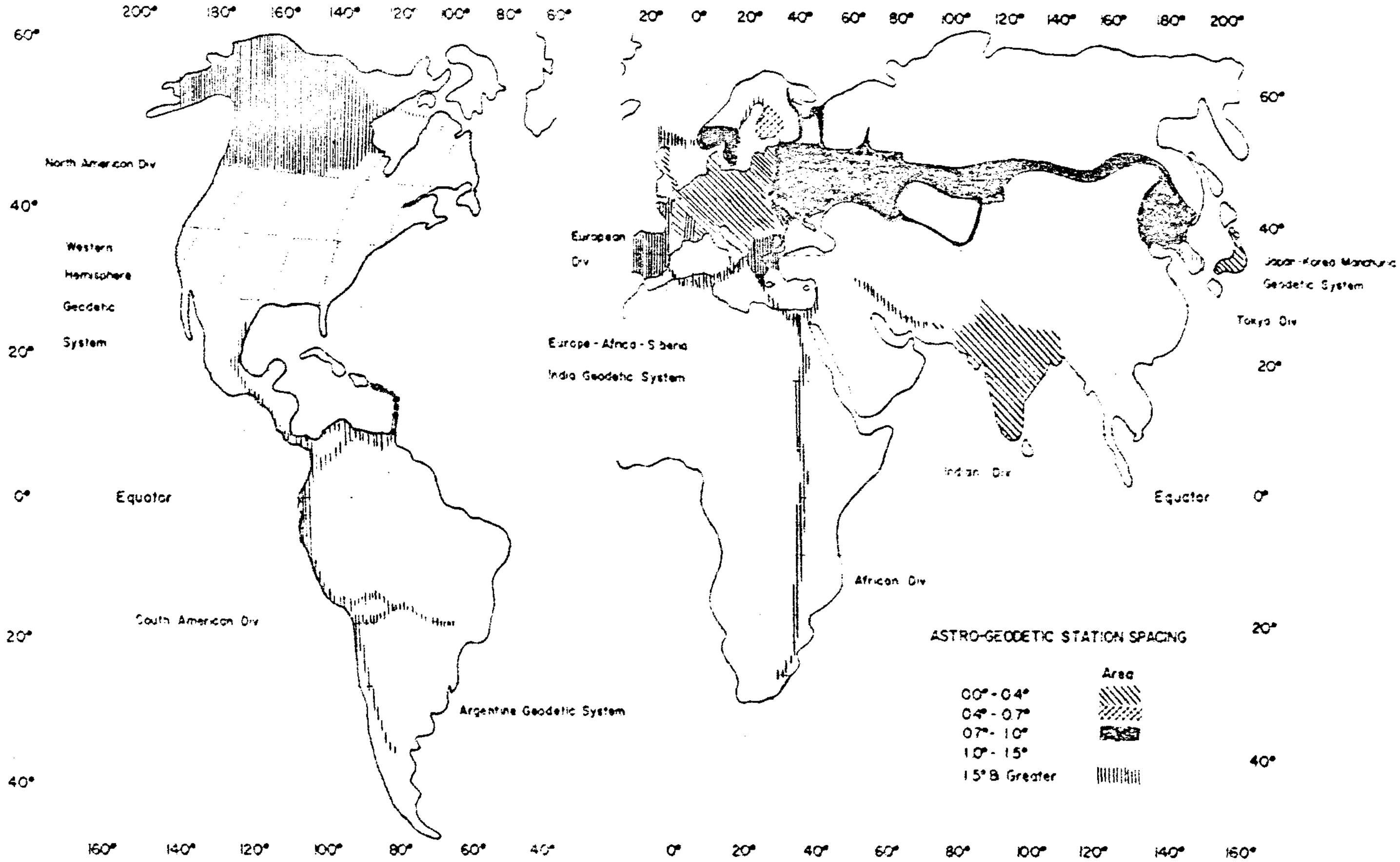
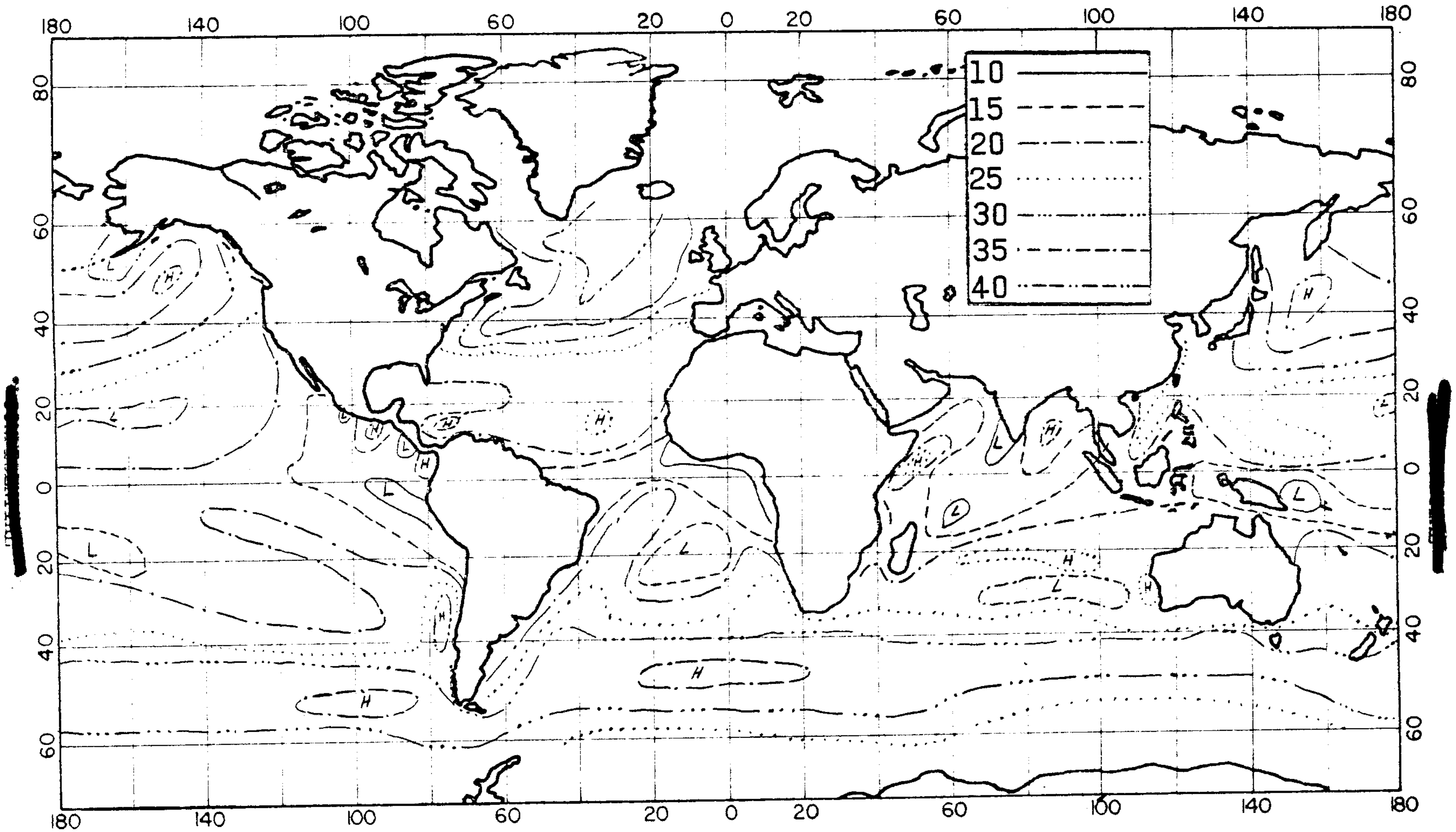


Figure 48.- Astro-geodetic geoid data station spacing and distribution.

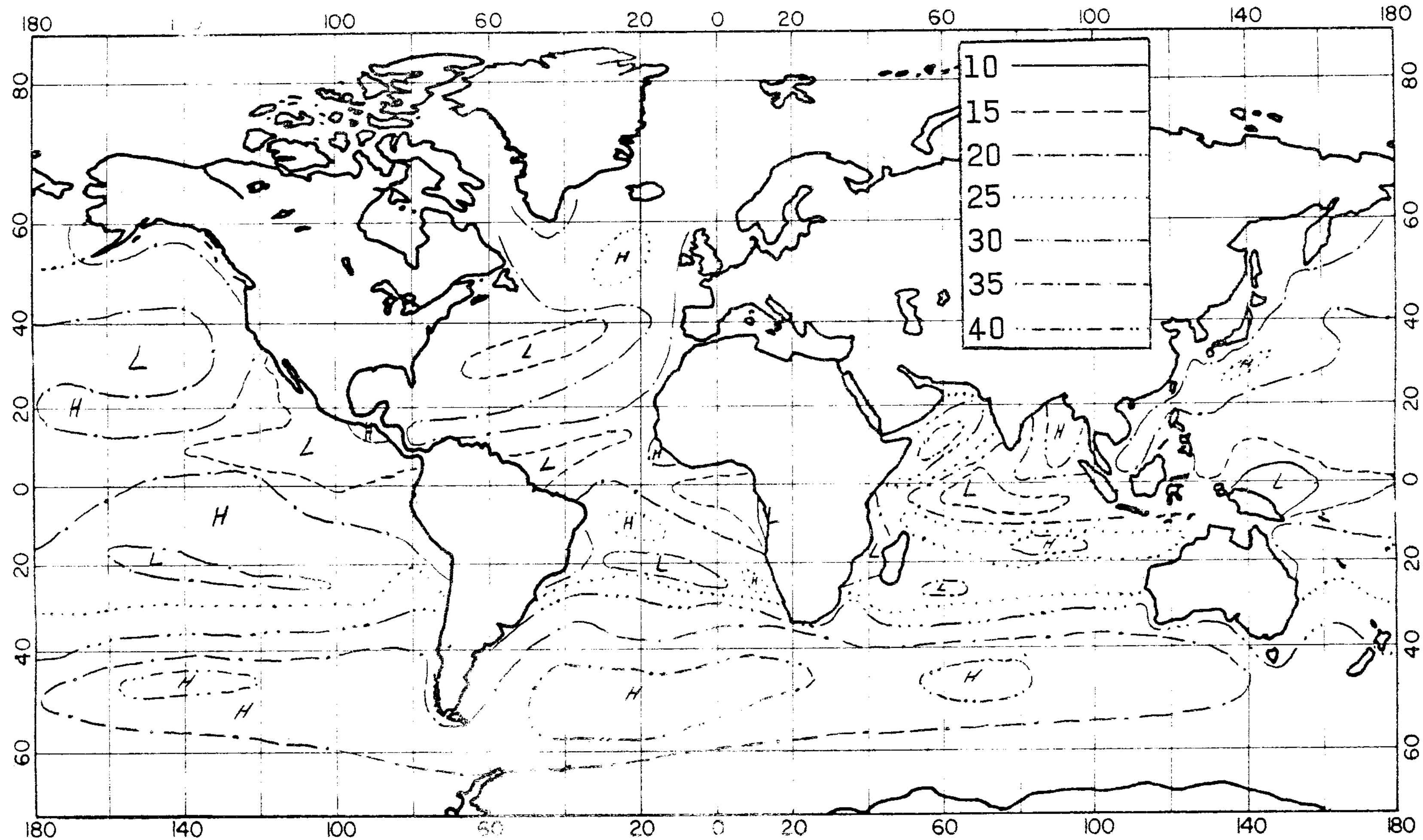
[redacted]



(a) January.

Figure 49.- Wind speed (knots) exceeded 10 percent of the time.

[redacted]



(b) July.

Figure 49.- Concluded.

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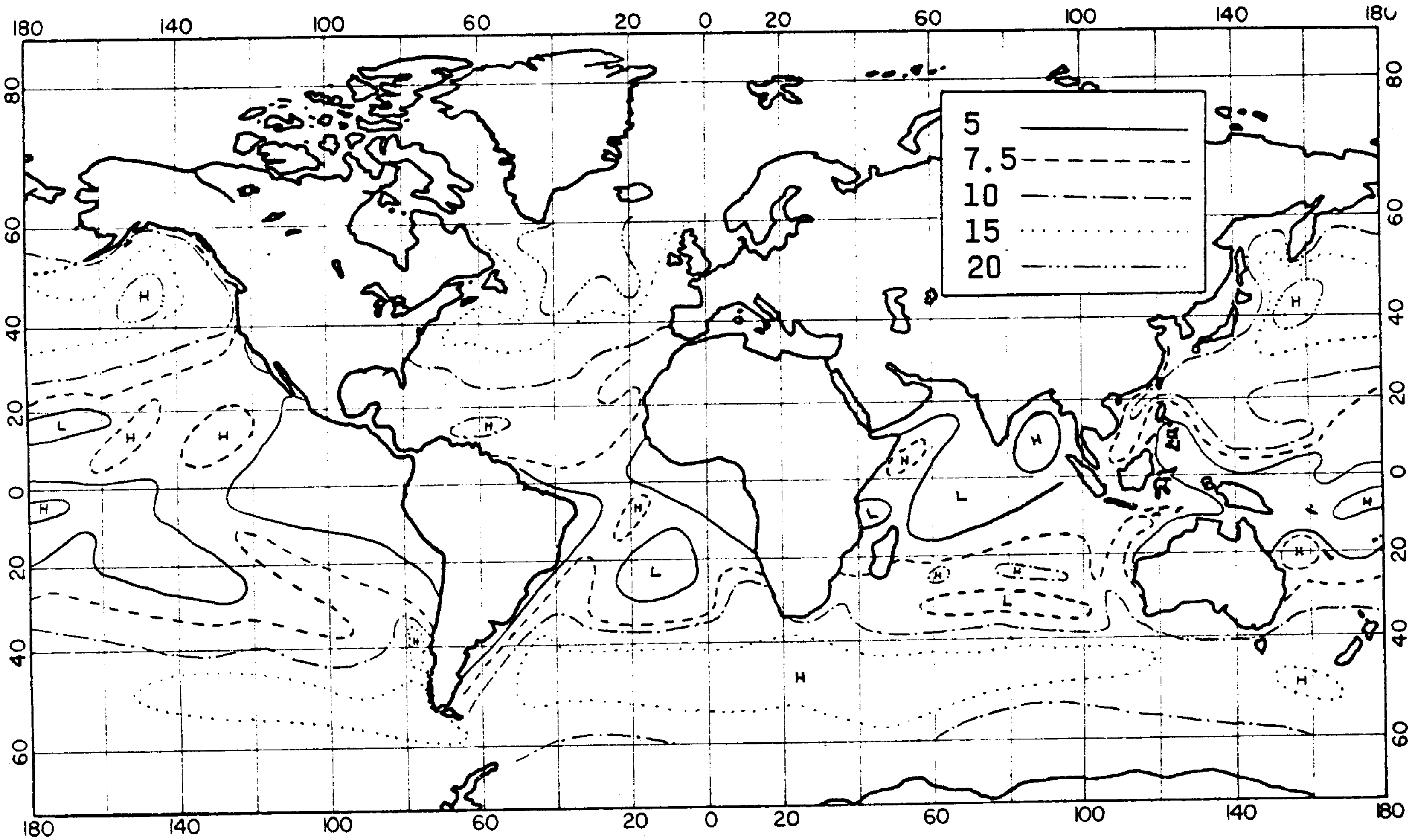

(a) January.

Figure 50.- Wave height (feet) exceeded 10 percent of the time.

[redacted]

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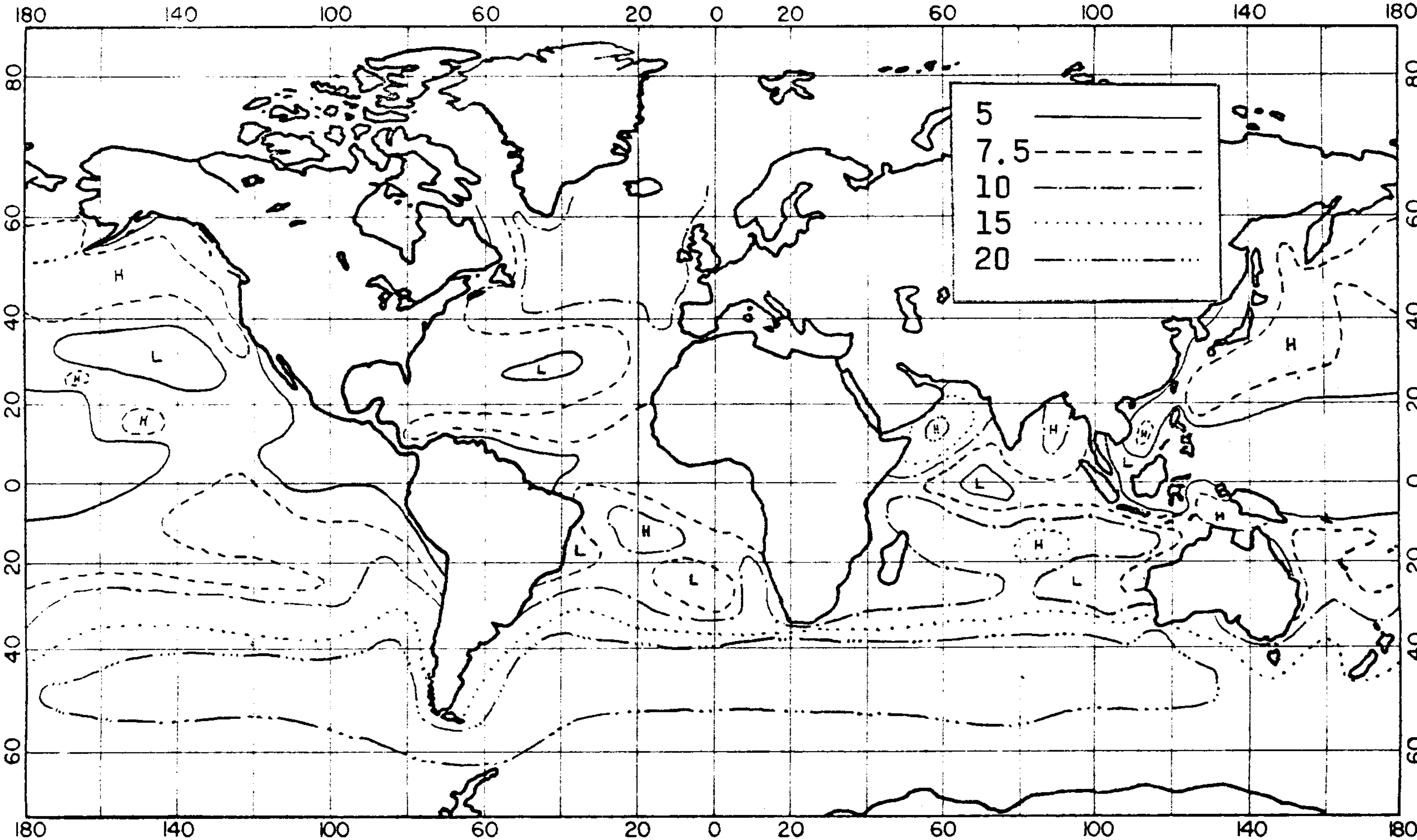

(b) July.

Figure 50.- Concluded.

[redacted]

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